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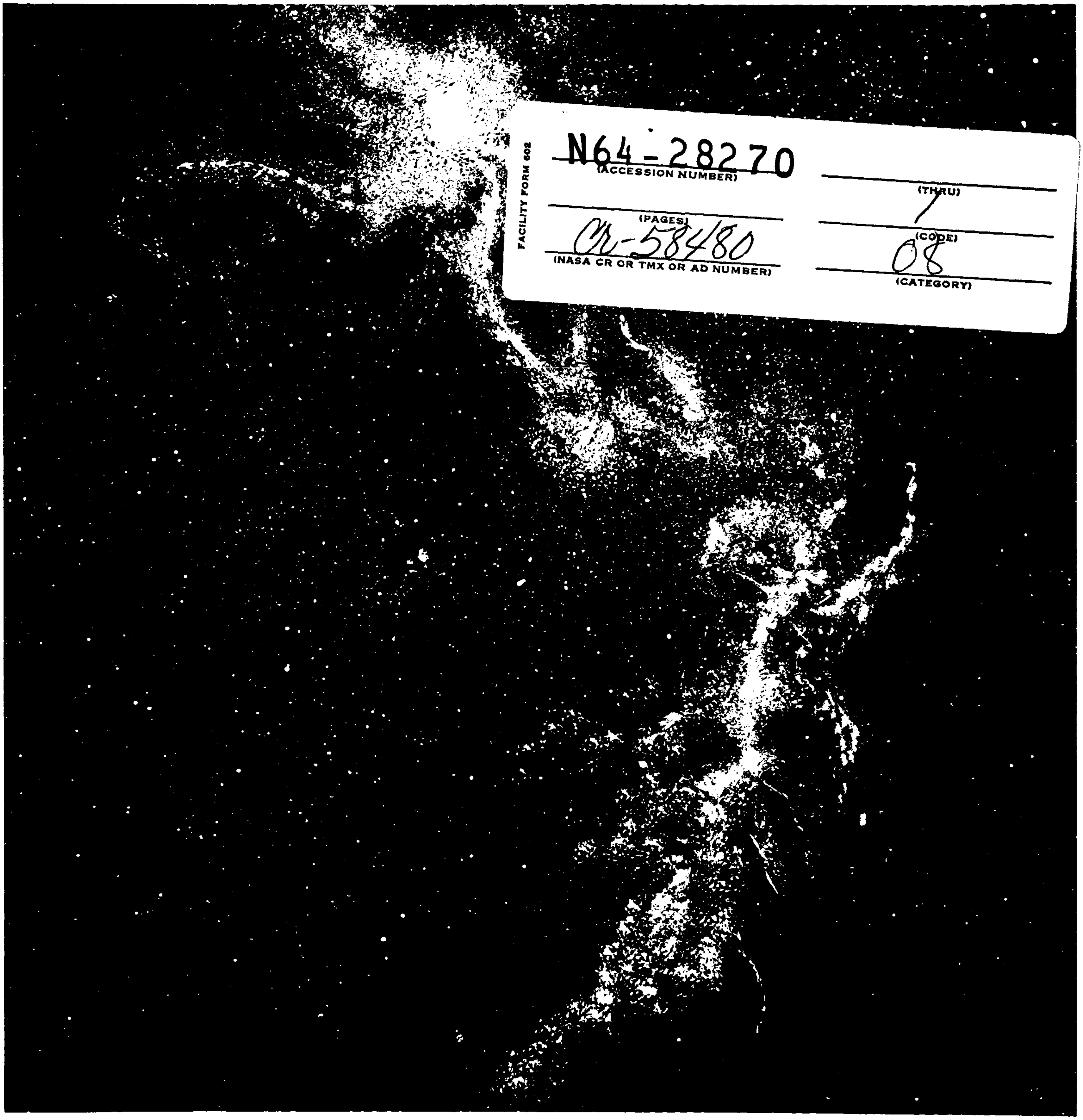

Research on an Advanced NASA Information System

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TRW COMPUTER DIVISION
THOMPSON RAMO WOOLDRIDGE INC.

RESEARCH ON AN ADVANCED NASA INFORMATION SYSTEM

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TRW COMPUTER DIVISION
THOMPSON RAMO WOOLDRIDGE INC.
CANOGA PARK, CALIFORNIA

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1. SUMMARY

This report discusses research covering five separate, but closely related studies on an advanced scientific and technical information system. The fundamental problems of an information system are (a) non-selection of pertinent material, (b) selection of non-pertinent material, (c) assimilation of selected material. (By assimilation we mean the incorporation of new material into an existing information processor in such a way as to become a functional element of that processor.) These problems appear in all basic system operations from the operation of acquisition to the operation of retrieving a specific document for a specific request.

The analysis of these problems as they particularly apply to the goals of the NASA information system and new approaches to their solution are therefore the purpose of this research. Author

The first study, Advanced NASA Information System, discusses the basic system functions and operations. A "spectrum" of operations is defined as a set of selection procedures. Each operation gives rise to the two types of errors defined by problems (a) and (b) above. It is clear that if data on these errors is available, then there is a possibility of establishing a negative feedback loop to improve the system operation. These possibilities are examined for each operation from acquisition to specific document retrieval. A study is also made of the role of automation. Besides a discussion of the applicability of automatic procedure, there is an examination of the problem of quality control, based on the three notions of feedback, monitoring, and systematic testing. Finally, a schematic of a future NASA information system is presented.

The purpose of the second study, Quality Identification, is to create a usable definition of the quality of a document from two points of view: its adequacy to satisfy an information need, and its potential for idea stimulation. A "quality profile" for a document is developed based on these two aspects of the notion of quality. Rating forms for recording the quality profile were designed and tested with promising results.

The third and fourth studies, Fragment Retrieval and Information Correlation are experimental approaches to the problem of assimilation

of selected material at the operation level of retrospective general search. In a technical information system we suppose that users will want output in order to (a) verify hypotheses or answer questions, (b) form new hypotheses. The fragment retrieval and information correlation experiments present approaches to the assimilability problem for the first and second purposes, respectively.

Experiments were designed to test the following assumptions:

Assuming that fragments of documents are easier to assimilate than entire documents, a study was undertaken to determine whether document fragments could provide adequate responses to retrieval requests. Results of retrieval experiments were positive; in 90% of the cases where complete answers were retrieved, those answers were contained in fragment sets having an average of 12 sentences.

Assuming that structured information is easier to assimilate than unstructured information and consequently that degrees of assimilability correspond to degrees of structure, two different degrees of structure were developed for a set of fragments. The structured data was then tested for assimilability by asking consultants to derive inferences from the fragment sets. Results indicated that inferences derived from the more highly structured material were considerably more homogeneous.

The fifth study, System Effectiveness, attacks the problem of how to measure quantitatively the effectiveness of a selection procedure. The study is general, and applicable to any of the system operations defined as selection procedures. The adopted measure is derived by two independent analyses. This supports the conclusion that the adopted measure is a "natural" one. The measure permits the graphical characterization of system effectiveness. The use of this characterization is discussed.

2. INTRODUCTION

2.1 NATURE OF THE NASA INFORMATION PROBLEM

Knowledge has been defined by NASA as the common requirement and principal product of all its scientific and technical programs. The goal of the NASA information program thus becomes the communication of knowledge—more specifically, the communication of knowledge derived from sources external to the NASA community, as well as the communication to the public of knowledge resulting from NASA-sponsored research.

An attempt to communicate all knowledge to all users, however, would be an absurdity. The body of knowledge relevant to the national aeronautical and space effort is formidable in size and extremely varied in content; moreover, its size is not likely to become less formidable nor its content less varied in the future. NASA's present and future information problem is therefore one of selection: what type of information should be disseminated to what persons.

The NASA information system can then be viewed as a series of selection procedures based on matching information requirements against information stores.

2.2 RESEARCH ON AN ADVANCED NASA INFORMATION SYSTEM

In the course of this study, we have attempted to define those selection procedures which are the basic components of an advanced information system and to demonstrate their interrelationships within such a system. The criteria for these procedures, their potential for feedback improvement and susceptibility to automation are discussed in Section 3, which considers the design of an advanced NASA information system.

Experiments with novel concepts in information processing are treated individually in Sections 4, 5, and 6.

A generalized evaluation procedure for measuring the effectiveness of the series of selections which constitute the operations of an information system is presented in Section 7.

2.3 CONTRACT GOALS

This research is responsive to articles I and II of NASA's contractual requirements as follows:

Section 3 (An Advanced NASA Information Study), Section 4 (Quality Identification Study), Section 5 (Fragment Retrieval Study), Section 6 (Information Correlation Study), are responsive to "... system analyze the acquisition, storage, documentation and dissemination elements of the NASA scientific and technical information system to determine the efficiency of their interrelationships and to determine the degree to which feedback on the quality of the information provided to the user can be used to improve the system... [This will] lead to recommendations concerning the future goals of a NASA information system."
Section 7 (System Effectiveness Study) is responsive to "... provide tools for measuring the effectiveness of a NASA information system and for testing the foregoing concepts."

3. ADVANCED NASA INFORMATION SYSTEM

3.1 INTRODUCTORY REMARKS

Information systems in the field of scientific communication have three main objectives which can be stated as follows:

1. announcement: dissemination of documents, publication of abstract journals, annotated bibliographies, lists of titles, etc., to notify users of new material entering the system;

2. idea stimulation: collections of significant research reports to provide a source of new ideas (professional journals are one example of this type of collection);

3. retrospective search and retrieval: outputting of particular documents or information in response to a specific request.

The present NASA information system can meet these requirements only in a limited sense, as it is yet in the early stages of development. The announcement function in the present system is satisfied by the semi-monthly publications of STAR and the International Aerospace Abstracts (IAA) which also carry out the function of idea stimulation to a limited extent, since they contain abstracts of documents collected together under particular subject headings. NASA is presently expanding its announcement capability through an experiment with selective dissemination of information based on user profiles. The search and retrieval function is satisfied by filling requests for particular documents or for bibliographies, in some cases annotated, on specific subjects. This also includes "repackaging" operations, such as compilation of conference and symposium proceedings, state-of-the-art monographs, handbooks, etc., which are essentially responses to anticipated information requests.

While NASA seems to be pursuing a correct course in expanding the operation of its information system, some questions should be raised regarding the content of that system. There is some evidence that NASA's basic information needs in terms of published literature are in a period of transition. A study* of the information requirements of the Redstone complex revealed that scientists and librarians were far more concerned with access to scientific journals than to technical reports collections. This reflected the fact that NASA was appointing increasing numbers of scientists engaged in basic, rather than mission-oriented, research. Their sources of information were the scientific journals. For these men, the technical report was an end product representing applications of research, not a source of fundamental information or stimulation.

NASA has taken cognizance of these needs in the IAA publication which with STAR gives comprehensive coverage of both published and unpublished material in aeronautics and space technology. Nevertheless there is some doubt that this constitutes the total body of literature essential to the NASA effort. It appears that an advanced NASA information system should be increasingly concerned with the open, general scientific literature.

Moreover, there is currently a critical need for high-quality reviews and syntheses of the scientific literature as well as guides to that literature. Since basic research tends to have an interdisciplinary character, this type of publication is an invaluable aid to the scientist who must frequently venture into a literature previously unknown to him.

A requirement for an increased translation capability within NASA is also strongly expressed. The time lag between publication and translation of the report of significant research conducted in other countries is often considerable and is unquestionably a cause of much duplication in research effort.

3.2 FUNCTIONAL RELATIONS BETWEEN ELEMENTS

Although properly oriented with respect to the three fundamental objectives discussed above, the present NASA information system has not yet fully exploited their potential. If we assume that the three basic elements of an information system are the documents, the queries, and the

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*Orne, J., Shipman, J., Vosper, R.: Report of a Survey of Library Facilities at Redstone Arsenal, June 1961 (Internal Note, Research Projects Division, George C. Marshall Space Flight Center, Huntsville, Alabama.)

users, an examination of the relations between these various elements exposes some interesting possibilities for expanding these functions to their fullest potential.

The relations to be considered first are:

(1) All users which match (are to receive) a particular document.

(2) All documents which match (are relevant to) a particular query.

(3) All queries which match (are generated by) a particular user.

These relations are indicated in Figure 1 by the arrows with clockwise direction. Relation 1 is the function of announcement and dissemination, relation 2 is the function of retrospective search, relation 3 represents the propagation of ideas of a user.

Consider next the set of converse relations:

(1') All documents which match (have been found relevant) to a particular user.

(2') All queries which match (led to relevant retrieval of) a particular document.

(3') All users which match (have formulated) a particular query.

These are indicated in Figure 1 by the arrows with counterclockwise direction. In each case, the data furnished by these relations can be used in a feedback improvement procedure for the functions of announcement, retrospective search, and idea stimulation. Thus the data in (1') establishes a field of interest of the user and can be used to modify the user profile data, hence improving the announcement - dissemination function. The data in (2') yields possible new associations of words with a document and thus an improved indexing and consequently an improved retrospective search. The data in (3') identifies users with a common interest. This leads to the novel possibility of an information system which facilitates new communication links between users.

In addition to these six relations there is another relation of interest, namely a relation between documents and documents: all documents which match (cite) a particular document. Such a set of documents serve as a citation index to a particular document. The role of such an index in idea stimulation has been emphasized before.

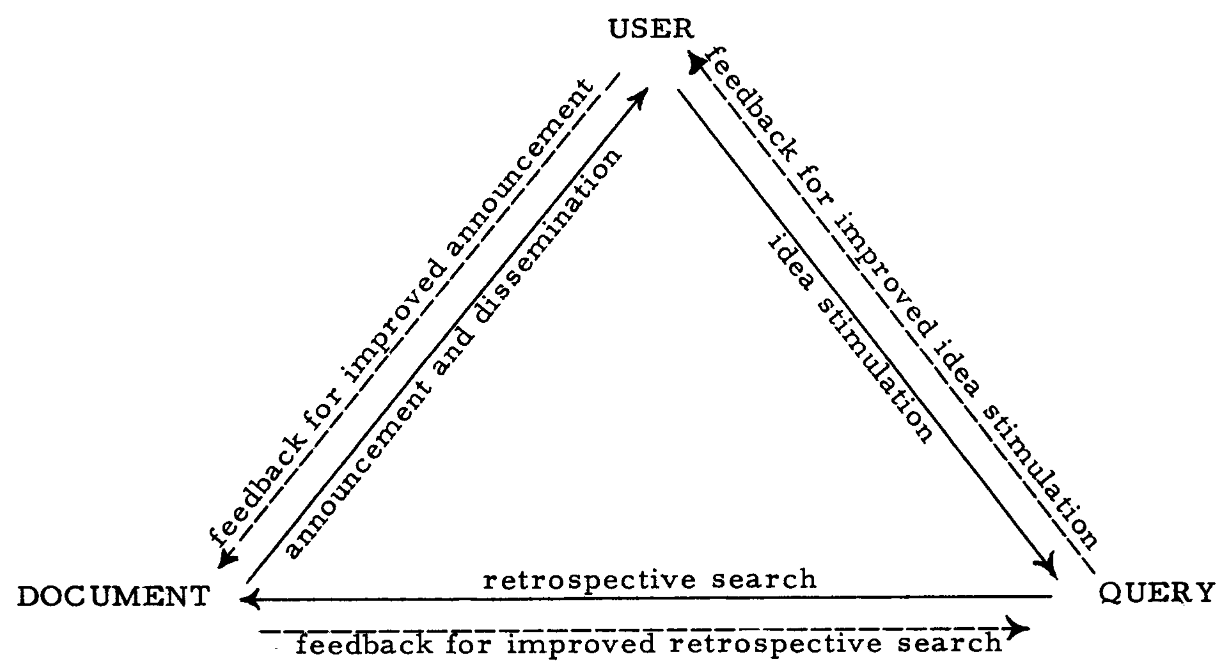

Figure 1. Interrelations between the Three Elements of an Information System

3.3 OPERATIONS OF THE NASA INFORMATION SYSTEM

Let us examine the notions expressed above in more detail. The fundamental operation of any information system is obviously that of matching user information needs to file items, say documents. This matching is the selection of documents from some population according to specific criteria. It is useful to form a hierarchical classification of these operations. This is shown in Figure 2. Thus the operation of acquisition is that of selecting documents relevant to NASA users from the entire "universe" of documents. The operation of grouping documents in the abstract journal is that of selecting documents relevant to a particular group of NASA users from the collection of acquisitions, etc.; finally, the operation of retrospective search is that of selecting documents relevant to a user's most specific information query.

The selection procedure is generally accomplished by matching representations of these things (conventionally called "indexes") rather than by directly matching information needs to file items. Let us define a rather detailed type of representation of a document.

(1) Title, author, accession number.

(2) A set of retrieval tags (e.g., keywords or descriptors). Without loss of generality we can imagine these to be "concept" or content indicators each of which represents a list of words all equivalent for retrieval purposes (e.g., a keyword together with its synonyms). Such a class of words we will call a thesaurus group, and the tags assigned will be taken to be thesaurus group designations.

(3) Subject categories (e.g., "Nuclear Physics", "Advanced Propellants"). This represents the assignment of a document to a classification category in the abstract journal.

(4) Assignment to abstract journal. We note that the decision to include a document in the abstract journal or not can be thought or as a rudimentary form of indexing.

Not related to this is another form of indexing, namely:

Query-Profile Type	Name of Operation	Query-User Profile (Information Needs)	Selection Criteria (Representations for Matching)	Type of Output
1	Retrospective Specific Selection	Request for a specific document	Accession number, title, author	Individual document
2	Retrospective General Selection (Information Retrieval and Literature Search)	Request for documents to answer a specific question. (This and the above are user profiles at a single instant)	Content indicators, keywords, descriptors 'tight' thesaurus groups.	Documents responsive to query
3	Projective Specific Selection: Dissemination	User-profile: stipulation of fields of interest.	Combination of content indicators	Lists of documents, bibliographies, groups of abstracts, groups of documents
4	Projective General Selection: Announcement of Acquisitions	Profile of a particular collection of users: group profile.	Subject Categories (e.g., "Nuclear Physics" "Advanced Propellants")	Groups of document abstracts under single classification in abstract journal.
5	Acquisition	Profile of all NASA users.	Designation of NASA mission	All NASA acquisitions.

Figure 2. System Operations as Selection Procedures

(5) Quality Identification Data. (See Section 4.)

Finally, let us include

(6) Citation Data. These will be a record of documents which cite the particular document represented.

Analogously, we define a hierarchy of representations of information needs of users; we call these representations query-user profiles:

(1) request for a document by stipulation of a particular title, author, accession number.

(2) request for documents covering particular concepts; thus represented by thesaurus group designations or content indicators.

We can interpret the above requests as comprising a user-profile at a particular instant in time.

(3) User-Profile: stipulation of fields of interest of a particular user by combinations of content indicators.

(4) Group-Profile: stipulation of fields of interest of a group of users.

(5) General-Profile of all NASA Information System users. It is convenient to define certain files in which this data is recorded:

(a) library file: consists of representations of documents;

(b) query file: consists of the requests described in (1) and (2) above;

(c) user data file: consists of the profiles described in (3) above.

The reader is referred to Figure 2 for the relation between the system operations and the matching criteria. The table is of particular interest as an indicator of the sources of data to improve these operations. This is discussed in the next section.

3.4 SOURCES OF FEEDBACK DATA FOR OPERATION IMPROVEMENT

3.4.1 Acquisitions

The data sought for modification of acquisition policy can be conveniently classified according to the two types of acquisition error: (a) failing to select material pertinent to the NASA mission; (b) selecting material not pertinent. This classification is reflected below.

Data from Documents

(a) The reference sections of documents acquired and judged appropriate to the NASA mission will reveal documents not acquired as well as sources of such documents. These sources can then be tapped to improve acquisition.

(b) If certain documents within the system are never cited by other documents in the system, we can construe this as an indication of their possible irrelevance to the NASA mission. Analysis of the source and content of such documents may lead to modification of acquisition policy.

Data from Queries

(a) Requests for specific documents not in the system reveal errors in acquisition. These data can be tabulated, organized, and analyzed. Perhaps new trends in demands will be revealed and consequently lead to modifications in acquisition policy.

(b) Data can be tabulated on the frequency of retrieval of documents via queries of types 1 or 2 (See Figure 2). Documents with a low frequency of use can be analyzed to revise acquisition policy. The obsolescence of documents will also be revealed by the change in frequency of use.

Data from User-Profiles

(a) The user-profiles (types 2 and 3, of Figure 2) may have concepts not related or only distantly related to concepts in documents already in the system. These data can be collected to revise acquisition policy according to user demand. The changing pattern of the user-profiles thus will reveal new trends in demands.

(b) Some documents in the system (as represented by their content indicators) may not match any user profile. As above, these data will reveal errors in acquisition.

3.4.2 Projective General Selection - Organization of Abstract Journal

The chief function here is the announcement of acquisitions. The organization of the journal can conceivably be used to stimulate new ideas by the association of the abstracts. An approach to this problem is not to associate the abstracts by *a priori* classification, but to use a completely empirical method.

Data from Documents. The document representation as a set of content indicators can be used to calculate the "relatedness" between documents, as a measure of concepts held in common. These measures can be used to "cluster" the documents. The clustering technique discussed in Information Correlation Study of Section 6 can be used for this purpose.

It is also to be noted that the concepts can be "weighted" if NASA policy is to emphasize particular problems. Similarly, the documents can be weighted by quality identification criteria (see Section 4) so that certain groupings can be emphasized.

The abstracts will not necessarily appear in unique classifications in this arrangement.

Data from User-Profiles. The user-profiles (type 3) can be similarly clustered. The document abstracts can then be classified to reflect the clustering of user-profiles. That is to say, a cluster of user-profiles will give a distinguished set of concepts, and documents which closely match this set of concepts are so classified.

The notions developed here are suggested by the Information Correlation Study (Section 6).

3.4.3 Projective Specific Selection-Dissemination

There are two methods of improving this function: the first is to improve the representation of the particular user; the second, to improve the representation of the document. We will discuss the second approach in 3.4.4. We consider here the changing pattern of interest of the user.

Data on Documents. By analyzing tabulated data on those documents found relevant to the user in the past we can modify the set of content indicators of the user's profile.

Data on Queries. Periodically we take the data from the query file that pertains to the user and use this to update the user profile by adjoining appropriate content indicators.

Data on User. Update file by instructions from user.

3.4.4 Retrospective General Selection - Information Retrieval and Literature Search

The problem of improving the indexing of a particular document can be seen to be conceptually equivalent to that of modifying the indexing method. For purposes of discussion let us suppose the indexing method to be an operation of assigning thesaurus group designations and the modification of the indexing method to consist of redefining the thesaurus groups. By thesaurus group we mean a set of words which are equivalent for retrieval purposes rather than a set of synonyms.

Data on Queries

One source of data is that provided by the user himself through a feedback of evaluation of relevance of output to query. Suppose word A occurred in a query which produced a relevant document containing word B by a match between A and B through membership in the same thesaurus group. This would then be tabulated as a "success." On the other hand if the document were irrelevant, this association would be tabulated as a "failure." These data could then be organized into a matrix of probabilities of success or failure, and used to reorganize the thesaurus groups.

This method has a disadvantage in that it only corrects false associations of retrieval equivalents. Another approach is to consider queries which produced no relevant documents initially, but upon reformulation by the user produced relevant documents. The variation of words in the query then should reveal new candidates for retrieval equivalents.

A third approach is by monitoring the indexing. This is described in Section 3.5.

3.5 CONSIDERATIONS FOR THE DESIGN OF AN AUTOMATED SYSTEM

In any conceptualization of an advanced information system, automation becomes a prime concern; considerations of information volume and user access time immediately suggest the desirability of automatic processing. Moreover, the notion that the output of library operations can be viewed as a set of selections (see Figure 2) is an additional argument for automation, since these selections are based on matching procedures and matching is an operation at which computers excel. Thus, the fundamental issue for the information system of tomorrow is not whether automation is desirable but how to exploit fully the potential automation holds for system growth. The latter concept involves three basic considerations:

(1) how much of the system can be automated?

(2) how can the quality of the automatic processing be controlled?

(3) how can automation be introduced into an existing system?

These three topics will be discussed below in turn.

3.5.1 <u>How Much of the System Can be Automated?</u>

The answer to the first of these questions is that essentially any matching procedure for which data and machine-recognizable criteria exist within the system can be automated. Quality identification would thus be substantially excluded from automatic processing, since it is based on criteria which are not machine -recognizable--namely, subtle human judgments of relative value. The basic acquisition process would likewise be excluded, as it involves a selection procedure from the universe of data outside the system. All other operations of an information system are susceptible of automation.

The first step in any information system is input. What will constitute the input to the system for a particular document is dependent on what types of processing the document will undergo throughout the system. If no automatic processes involving the entire document (e. g., automatic abstracting or translation, or automatic indexing based on the full text) are contemplated, input may consist of title, author, and accession number only, or of these plus first and last paragraphs, citations, abstracts or other input requirements dictated by the design of the system. Since our conceptualization of an advanced NASA system does require access to the entire document, we assume that this is the desired input. Input may be accomplished via keypunching, paper tape, or optical scanning device. The storage medium for all automatic components of the system is magnetic tape (thesaurus, translation dictionary and algorithms, query user files, document files, etc.).

If the incoming material is not in English, its contents are first converted automatically to sets of English equivalents, grammar codes, and semantic information by matching against a machine dictionary. Translation is then implemented by application of syntactic and semantic algorithms to the output of the dictionary lookup.

The material must then be indexed, or converted into the form by which it will be represented in the series of matching procedures, or system operations, which follow. The words of the document are automatically matched against a stratified thesaurus, converting the document into a set of hierarchically structured thesaurus groups. At this stage, data from the document references will be processed to update citation indexes.

A screening of documents for relevance to NASA's mission is then accomplished automatically by matching the set of thesaurus groups representing the document against a set of thesaurus groups compiled from the individual user profiles, representing the general interest profile of users of the NASA information system. If matches are found, the document is output for quality analysis by a technical staff. Based on the quality judgments made by the analysis, the document may re-enter the automatic system with appropriate coding to reflect these judgments, or may be discarded.

Upon re-entry into the automatic system a check is made of the quality coding to determine whether the document should be announced in the abstract journal and/or disseminated to individual users, or enter the system without announcement. If the latter decision is made, abstracting the document is optional. Otherwise a descriptive abstract of the document will be produced automatically. *

Two different matching procedures are involved in the operations of announcement (projective general) and individual dissemination (projective specific). Processing for announcement in the abstract journal consists in automatically matching the set of thesaurus groups representing the document against the set of thesaurus groups representing the major subject classifications into which material in the journal is divided. ** An alternative automatic procedure is the empirical grouping of abstracts by clustering techniques (see Section 3. 4. 2 above). The subject index to the journal is automatically compiled by sorting thesaurus groups representing

* See "Automatic Abstracting," TRW Computer Division, Thompson Ramo Wooldridge Inc., C107-3U1, 2 February 1963.

** Our previous investigations have shown that only 12 words in the field of nuclear physics suffice to characterize a document on nuclear physics, and that a successful classification rule was that any nuclear physics document must contain at least two of these words - it is presumed that similar sets of words characterize other fields. See "Word Correlation and Automatic Indexing" Progress Report No. 3, TRW Computer Division, Thompson Ramo Wooldridge Inc., C82-1U2, January 1961.

each particular document according to frequency and using the designations of groups with the highest frequency of occurrence as the subject index terms. Abstracts for documents classified under particular subject categories and the accompanying indexes are output in an automatically composed format suitable for microform or hardcopy print processing.

Processing for individual dissemination involves automatically matching the set of thesaurus groups representing the document against a set of thesaurus groups representing a file of the interest profiles of individual users. For those users for which matches are found, an abstract tailored to the stipulation of interest of the individual user (an optimal document fragment) is produced automatically by weighting most heavily words contained in the thesaurus groups which make up his profile. These abstracts are then automatically composed into a format suitable for microform or hardcopy print processing and are output for print processing and distribution to the user.

A second input to the system are the natural language queries sent in by users. These queries may address either the retrospective specific (request for a specific document) or the retrospective general (all other queries) operation, each of which is based on a different matching procedure. The request for an individual document may only require automatically matching the accession number given in the request against a tape file of all documents in the system sorted by accession number. If no accession number is given, matching against a file sorted by title, or if this is unproductive, by author, may serve. The document is then output in a form suitable for the type of print processing stipulated by the request.

The second type of query entering the system is a request for documents to answer a specific question, which may ask for all information on a particular subject or combination of subjects (literature search) or may ask for a particular piece of information (information retrieval). In either case, automatic processing of the query involves two matching procedures. The first of these is a thesaurus lookup, which produces a search prescription by matching words in the query against words in the thesaurus and assigning a set of appropriate thesaurus groups to represent the query within the system. This set of thesaurus groups is then matched against the set of thesaurus groups representing all documents contained in the system to determine which documents are responsive to the given request.

The output for a literature search request may consist of a bibliography, a list of document identifications (title, author, accession number), or an annotated bibliography, a list of document identifications plus abstracts, or a set of relevant document fragments, or a set of relevant documents. The output for an information retrieval request may consist of a set of relevant document fragments or a set of relevant documents. All of these outputs may be automatically arranged in order of most probable relevance to the question by sorting the documents according to frequency of occurrence of thesaurus groups representing the query. Alternatively, the outputs could be automatically grouped by the application of clustering techniques (see Section 3. 4. 2 above). The final step in automatic processing of these search results is composition into a format suitable for microform or hardcopy print processing, or a screen display.

In summary, the primary operations of an advanced NASA information system consist of a particular series of matching procedures between three basic files:

(1) the "library" file - tape files of all documents; tape files of documents sorted according to accession number, title, author, thesaurus group, citations, quality coding, and frequency of usage.

(2) the user data file - tape files of interest profiles and related data on individual users of the system; tape files of user data sorted as to name, affiliation, thesaurus groups representing area of interest, authors and articles cited.

(3) the query file - tape files of all queries which have entered the system; tape files of queries sorted according to thesaurus group, type of request (literature search, information retrieval, specific document), type of output (bibliographies, fragments, abstracts, documents), documents responsive to request, and requestor.

3.5.2 How can the quality of automatic processing be controlled?

There are three answers to this question. The first of these is through a series of feedback operations, which, like the primary operations discussed above, consist of a particular set of matching procedures between the three basic files, and thus present no special problems for automation. The potentialities of specific feedback operations for improving the functioning of the system are discussed in detail in 3.4 above.

The second answer is through human monitoring of all automatic processes. This could perhaps best be implemented by a display console, which would allow an information specialist to conduct spot checks on the results of automatic processing by calling for displays of indexed documents, of machine-produced abstracts, user profiles, and so forth; or to follow a single document or query through the entire cycle by displaying the output of the automatic process in sequence.

In converting from a partially mechanized to a fully (or as fully as is feasible, as discussed above) automatic system, a considerable amount of human monitoring is foreseen in the early stages. For example, an information specialist might request display of a portion of a document and the thesaurus groups by which the document was represented by an automatic procedure. If the automatic procedure has failed to assign thesaurus groups judged appropriate by the information specialist, this omission will generally be attributable to a deficiency in the thesaurus, which can be corrected by addition of new words from the document. If, however, inappropriate assignments have been made by the automatic procedure, deletions might be required in a whole series of related thesaurus groups and documents to which they have been assigned, a task which would be tedious with computer aids and impossible without them.

The man-machine relationship is thus one of mutual assistance; the machine assists the human by presenting in effect a reminder list of thesaurus group assignments which are based on unambiguous associations of words, while the human information specialist feeds back to the machine improvements and corrections to its thesaurus groups. The net result is better than either man or machine could realize unassisted, and at the same time builds a system whose performance is continually improving and continually susceptible to being measured, controlled, and diagnosed.

A third way of achieving quality control is through systematic testing. This can be accomplished by selecting a sample test library of a suitable size, and a sample of test queries. The retrieval effectiveness measures discussed in Section 7 can then be applied for a qualitative comparison of the various stages in the development of the system.

3.5.3 How can automation be introduced into an existing system?

The answer to this question is "gradually". A series of pilot experiments in automating various system operations within the state of the art can be conducted on a small scale relatively inexpensively. The results of these experiments can be used to improve the experimental design until a consistently reliable output is produced. If large-scale fully automatic processing is economically unfeasible with available equipment at that time, specifications can be modified to allow operation in a semiautomatic mode.

NASA has already made a good beginning in this area by initiating semiautomatic searching and dissemination procedures which are based on matches of manually assigned subject codes. No automatic processing has as yet been attempted on full texts of documents.

An intriguing possibility for a next step in NASA's scientific and technical information program would be the construction of a small-scale model of the advanced information system outlined in this section.

This would require sample library, query, and user data files, and a limited thesaurus on tape; programs for indexing and abstracting, as well as general purpose programs for editing, sorting, matching, merging, etc. Some of these automatic devices already exist as experimental tools; the creation of others would require a relatively small expenditure of funds and programming time.

This notion of an information system on a laboratory scale would permit the experimental testing of advanced concepts in a controlled environment. When consistent results have been achieved over a period of time, components of the model system could be introduced into the NASA system singly, for further testing on a limited basis in a real environment.

Thus it is possible to minimize any risk of deterioration in the quality of system operations as a result of introducing automatic processing into a semiautomatic system. In this way the potential for growth in the NASA system can be fully exploited to achieve the ultimate goals defined by the NASA scientific and technical information program.

3.6 OUTLINE OF A FUTURE NASA INFORMATION SYSTEM

The accompanying chart (Figure 3) shows the essential operations of an advanced information system and the conceptual relations among them. Annotation is provided by five sheets of commentary, to aid in reading the chart. Each box on the chart has been assigned a number; this number appears again, under the column "Boxes", identifying the commentary for that box. Arrows between boxes are uniquely identified by their points of origin and termination and are represented by pairs of numbers under the column "Arrows", where they identify commentary on the relation of boxes to boxes. The commentary and the chart are supplementary to one another, and are intended to be read in conjunction.

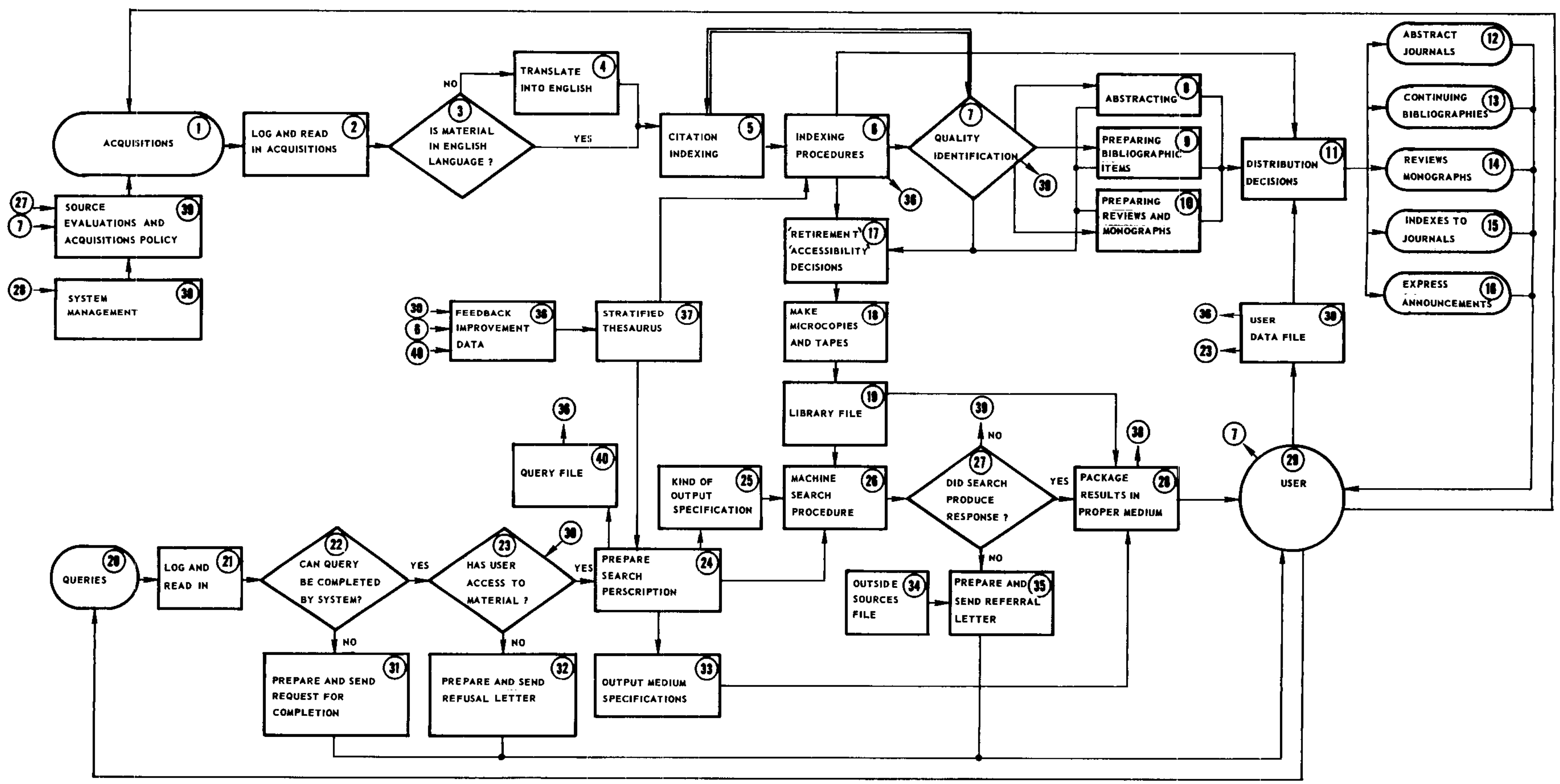

Figure 3. Schematic of an Advanced NASA Information System

BOXES

1. Acquisitions
   - (a) NASA technical reports, notes, reprints, memoranda
   - (b) Contractor reports
   - (c) Proceedings of conferences and symposia
   - (d) State-of-the art monographs
   - (e) Technical reviews and translations
   - (f) Handbooks and data compendia
   - (g) Dictionaries
   - (h) Books
   - (i) Journals

2. Log and read in: check for duplication of present library contents; review for relevancy to NASA interests; register into inventory.

3. Check whether material is written in the English language.

4. Translate: make note in translated material and in bibliographic data of original language and translator.

5. Citation indexing: continue or begin citations net.

6. Indexing procedures: produce machine representation of document.

7. Quality identification: classify breadth, technical level, kind of contribution, stimulation potential, estimated life of material.

8. Abstracting: review and edit author abstracts, prepare abstracts if needed, adapt and translate précis.

ARROWS

1-2. Send acquisitions on to (2).

2-3. Send logged-in material on to (3).

3-4. Send non-English material to be translated.

3-5. Send English material on to be citation indexed.

4-5. Send translated material on to be citation indexed.

5-6. Send material on to be indexed.

5-7. Citation indexing feedback to correct past quality identifications.

6-7. Send indexed material on for quality identification.

6-11. Send indexes on to be prepared for publication.

6-17. Send indexed material on to storage.

6-36. Feed back index data for thesaurus improvement.

7-5. Quality identification may suggest beginning a citations net.

7-8. If quality identification suggests that abstract of material is desirable, send material to be abstracted.

7-9. If quality identification suggests express announcement or inclusion in continuing bibliographies, send material for appropriate processing.

Figure 3. Commentary: Schematic of an Advanced Information System (Sheet 1)

BOXES

9. Gather bibliographic data (author, title, accession number, publisher, date, company, project, contract, security classification, and selected items from the quality profile) into standard format; sort in standard order.

10. Send material to be reviewed or included in a monograph; log in returned reviews and monographs.

11. Select items for users by interest profiles (cf. box 30).

12. Categorize abstracts for assembly and publication of journal sections; print.

13. Assemble and categorize continuing bibliographies; print.

14. Print reviews and monographs.

15. Prepare and print indexes to journal; periodically cumulate and publish cumulated indexes.

16. Prepare and print express announcements.

17. Decide how to apportion prime storage based on retirement and access criteria.

18. Produce microform and tape copies of the acquired material.

19. Library file of hard copy, microform and tapes.

ARROWS

7-10. If quality identification suggests treatment in a review or monograph, send material to experts for such treatment.

7-17. Send quality identification information to help with retirement and accessibility decisions.

7-39. Send quality identification information to help influence acquisitions policy: evaluation of sources of material in terms of value (for NASA public) of material.

8-11.) Send abstracts, bibliographic
9-11.) items, reviews and mono-
10-11.) graphs on to be sorted for distribution.

8-17.) Send abstracts, bibliographic
9-17.) items, reviews and mono-
10-17.) graphs to be classified for storage.

11-12. Send sorted material on to be published as abstract journal.

11-13. Send sorted material on to be published as continuing bibliography.

11-14. Send sorted material on to be published as review or monograph.

11-15. Send sorted material on to be published as index.

11-16. Send sorted material on to be published as express announcement.

12-29.) Send published material to
13-29.) users selected by interest
14-29.) profile.
15-29.)
16-29.)

Figure 3. Commentary: Schematic of an Advanced Information System (Sheet 2)

BOXES

20. <u>Queries</u>

(a) Complete requests for a specific document or documents.

(b) Incomplete requests for specific documents.

(c) Requests for all documents bearing on a stated combination of subjects.

(d) Requests for bibliographies, titles, abstracts or annotated titles bearing on a stated combination of subjects.

(e) Questions about various subjects, expressed in natural language.

21. Log in requests by requestor, date of acceptance, user affiliation, etc.

22. Determine whether the query contains sufficient information for the search procedure to identify responsive material.

23. Determine whether user has access to material (under security and proprietary restrictions).

24. Reformulate the user's query into a machine-readable search prescription.

25. Extract from the request information as to whether the user wants documents, abstracts, or bibliographic data.

26. Using search prescription, search library file for material relevant to request and output representations of the material.

27. Determine whether search produced any output.

ARROWS

17-18. Send material, with storage assignments, to be copied.

18-19. Send material to storage.

19-26. Load tape for machine search.

19-28. Locate master copies of items specified by search procedure.

20-21. Accept queries from user, register as to requester, date of acceptance, user affiliation, etc.

21-22. Pass logged-in query on for completeness analysis.

22-23. Complete query if possible and pass it on to determine whether user has access.

22-31. If query can not be completed by system - i.e., the requested material is unidentifiable, send on material for preparation of letter requesting further information.

23-24. If user has access, send his query on to be reformulated for machine processing.

23-32. If user is denied access, send this decision and his query for preparation of refusal letter.

24-25. Send request on for recording of output specification data (request for bibliography, documents, etc.).

24-26. Input search prescription to search procedure.

24-33. Send request for determination of specified output medium (hard copy, microfilm, screen display).

Figure 3. Commentary: Schematic of an Advanced Information System (Sheet 3)

BOXES

28. Put material into the proper output format: prepare hard copies, microcopies, or screen-displays; transmit (or display) this output to the requester.

29. Users of the NASA information system in general: industrial, academic, technical, administrative, etc.

30. User Data File: information, continually updated, on users of the NASA information system by name, industrial, academic and contractual connections, past publications and requests, volunteered information on interests, plans, present projects; security and need-to-know data.

31. Prepare letter explaining that the request is incomplete and requesting additional information.

32. Prepare letter explaining the difficulty in access.

33. Extract from the request whether the output should be hard copy, microcopy, or screen display.

34. Information as to where material not included in system is likely to be found.

35. Write letter informing user of failure of search and likely places to look for relevant material.

36. Feedback from user file, query file, and indexing procedure for thesaurus improvement.

37. Stratified thesaurus for coding of queries into search prescriptions, for preparing representations of documents, and for coding of user interest profile.

ARROWS

24-40. Send queries and requests on to query file.

25-26. Input to the search procedure the information extracted in box 25.

26-27. Search procedure outputs, document representations, or indication of failure to find responsive material.

27-28. If responsive material resulted from search, send on the representation to be prepared for presentation to the user.

27-35. If search failed, pass requests on for preparation of referral letter.

27-39. Send information to acquisitions department for decision as to whether missing material should be added to collection.

28-29. Transmit to user.

28-38. Send data of statistical significance as to what material is currently in most demand to management, for possible revision of acquisitions, storage policy, or search procedure.

29-1. Literature generated by users of NASA information system is acquired by the information system.

29-7. Feedback from the user aids in quality identification.

29-20. Unsatisfied or newly stimulated information needs of the user return to the system.

29-30. Additional information about the user's satisfaction with the retrieved or presented material.

30-11. Send user data information to aid in dissemination decisions: name, address, interests, technical level, etc.

Figure 3. Commentary: Schematic of an Advanced Information System (Sheet 4)

BOXES

38. Policy decisions affecting the whole operating system.

39. Acquisitions policy: decisions about the value of present or contemplated sources.

40. File of natural language queries and search prescriptions.

ARROWS

30-23. User data file: information on access.

30-36. Current trends in word usage for thesaurus improvement.

31-29.) completion)
32-29.) rejection) letters to requestor
35-29.) referral)

33-28. Send output medium specifications to packaging.

34-35. Send information as to where responsive information might be found.

36-37. Improvement of thesaurus by feedback.

37-6. Thesaurus used in indexing procedure.

37-24. Thesaurus used in request formulation.

38-39. System management determines acquisition policies.

39-1. Acquisitions policy determines the selection of input literature.

40-36. Feedback information on use of terms in queries for thesaurus improvement.

Figure 3. Commentary: Schematic of an Advanced Information System (Sheet 5)

4. QUALITY IDENTIFICATION STUDY

4.1 PURPOSE: CREATE A USEABLE DEFINITION OF QUALITY

There are explicit and implicit ways by which quality of documents is judged for others, especially on the professional level: explicitly in selection of articles for publication in professional and scientific journals and in the coverage of scholarly reviews and monographs, and in some cases implicitly in authors' citations of other documents. Editorial processing of scientific documents for publication includes screening to meet the standards of the presumed target reader group, and often includes submission of a document for evaluation to reviewers known to be competent in the same field. Authors of monographs or state-of-the-art reviews select that which appears to them most significant and exclude the trivial. It may be that citations can be interpreted as attributing some positive measure of quality to the referenced work.

This kind of selection, though the criteria are seldom elaborated in a systematic way, interprets quality for a certain kind of user. To extend an interpretation of quality to the needs of users in general, including the "experts," involves identifying the various kinds of factors which are likely to influence a judgment of quality. In this study quality is approached from the viewpoint of different kinds of users with different needs and abilities, and then an attempt is made to identify the projected requirements in documents.

Three different frames of reference within which the quality of a document can be judged are used in this study to define the concept "quality." The first relates to the user's needs, interests, and ability to respond at a given time. The second relates the document to a group of generally accepted standards for good workmanship and scientific adequacy in a document qualifying for publication. And the third relates the content of the document to the current frontier of knowledge and technology, and judges it as of high quality if it contributes new information and ideas, especially if these seem likely to influence the course of future work. To summarize:

"QUALITY":

(1) a relation to the user's needs, interests, abilities

(2) a relation to accepted standards for publication

(3) a relation to the frontier of knowledge

The main approach of information systems to describing document content has been subject indexing. Content description beyond this on various levels of generalization and abstraction has largely been left, by intent or default, to the reader. The present investigation, however, is addressed to the problem that a document may be completely relevant to a query and yet in addition be judged excellent or poor, significant or trivial, useful or not useful.

It is the purpose of this task to make a preliminary inquiry into those aspects, apart from subject relevance, which influence the "fit" of document and various kinds of users—that is, the successful transfer and assimilation of information, and its maximum exploitation in the solution of problems and as a basis for further work. These are related to "quality" since they participate in determining for a given user at a given time whether the document is then, for him, good or bad. But the term "quality" is here applied, not to the document with reference to some absolute standard, but rather to the "fit" on <u>each</u> occasion of interaction between user and document, or more widely, between the users and the information system.

Quality in this sense has three negative attributes:

1. It is not absolute, a priori
2. It is not machine recognizable as yet and may never be
3. It is not intrinsically quantitative

It is not absolute or machine recognizable because it depends on a complex interaction between abstract attributes of document, user, and the times, and it is not quantitative because these attributes are unlike in kind and cannot be summed. This is to deny the meaningfulness of a single numerical index to <u>the</u> quality of a document.

To illustrate the basis for these statements, we list the three classes of factors which participate in determining which of all the documents in the information system on a given occasion best serve a specified information need. From the factors to the left comes motivation to use the information system. Those listed to the right are attributes of the situation which hopefully the information system can identify.

Sources of motivation:	Attributes of Documents:
Information need	Subject content
Character and knowledge of user	Special character
Institutional initiative	Adequacy
	Breadth of applicability
	The State-of-the-Art
	(The context of what is currently known and what has already been achieved)

The superiority of the best document (or documents) which an information system should deliver on a given occasion is a function of (1) the information need—for example to become informed in a field new to the user, such as applications of lasers, (2) the content of all the various documents in the information system, and (3) the current level of knowledge and achievement. That is to say, a document excellent for a given information need at one time would become inadequate after advances in the state-of-the-art—a change external to both user and document content. The above factors will be discussed in turn.

a. Motivation:

(1) Information need has to do with the total of information existing in the literature which would be relevant and useful at a given time for a given situation. It is here defined with respect to problems rather than users and will often be an unexplored and undefined quantity. An articulated need such as a specific or standing request or selective dissemination profile may not encompass all that would be useful.

In the case of browsing, what the user seeks is undefined:

> "In many cases, especially in research, he goes to the library to interact with the literature. This is an active process, one in which the scientist's understood aims change steadily, both as a result of what he has found, and as a result of what he has accidentally noticed. The antithesis of the development man in search of specific information is the researcher who has come to browse."*

(2) Character and knowledge of the user is here used to refer to all personal attributes — such as current knowledge, intelligence, education, curiosity, ambition, professional role — which affect the kind of response a user is able and likely to give to a document in terms of interest and use.

(3) Institutional initiative refers to the possibility of an institution, such as NASA, interjecting its own orientation and purpose. NASA does do so implicitly by granting contracts and establishing an information system of specified scope, and it may become an even more active participant by taking the initiative in discovering information needs, distributing documents, arranging for preparation of summarizing and synthesizing literature such as compendia of data and methods, reviews, monographs, etc.

b. The Documents

(1) Subject content is the traditional criterion for indexing. It may be defined by terms found in the document, by their synonyms or related concepts as developed in a thesaurus, or by various level generalizations and abstractions attributed by reader or indexer.

(2) Special character of the document refers to such attributes as special emphasis, breadth of relevance, slant of interest, and technical level, etc. which may describe the content of a document apart from subject content.

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*J. W. Tukey. "Keeping Research on Contact with the Literature: Citation Indices and Beyond," presented before the Division of Chemical Literature, ACS National Meeting, Chicago, September 1961.

(3) Adequacy of document is a term used here to refer to attributes of a document related to accepted standards for publication: newness of content, scientific validity, clarity of expression.

c. The Times:

(1) State-of-the-art has to do with the relation of the document to current knowledge and technology, with whether or not it makes a new contribution.

The relative importance of the above aspects varies radically from one occasion to another. However, these describe the main elements in the interaction of user and document. If it were possible to identify for each confrontation of user and information system those aspects of greatest importance, and to select documents accordingly, a considerable economy in readers' time and perhaps in system cost would seem possible.

The hypothesis is here presented that, by careful analysis of the various attributes of quality, much of the judgment which a user exercises in screening documents, beyond and apart from subject relevance, can be moved forward in the document handling process and exercised in the information system. It is not suggested that present means of access to documents be replaced or curtailed. The aspect under consideration constitutes an optional new dimension in document handling. It is believed that quality identification, in the sense developed here, will make it possible to reduce the quantity of material presented to an individual, will make possible a more precise identification of both target document and target reader, and expedite routing information to those most able and likely to make use of it—for solving their immediate problems or as impetus to their own creative abilities.

4.2 SCORING OF QUALITY

Judging quality from the viewpoint of an information system involves exploring the possible usefulness of a document in terms of kinds of problems and kinds of users in order to maximize the exploitation of document content. Judging quality from the point of view of an individual user relates the document to his particular situation only, and may be couched simply in terms of his own satisfaction. That is to say, for the information system the concept of "quality" is used in the sense of "attribute" or "property," whereas for the individual user it may describe a value judgment.

4.2.1 Quality From the Viewpoint of the Information System

In this exploratory anatomy of quality, documents have been regarded from three different viewpoints. The first is represented in the "Survey" sheet of the Quality Profile. It is an overview, listing certain characteristics of readers and documents which may influence which particular documents will best serve a given information need on a particular occasion. Some of these characteristics imply directives to the information system. The second aspect is represented in the "Quality as Adequacy" sheet and relates to accepted standards for publication in terms of preparation and textual adequacy. The third aspect is represented in the "Quality as Stimulation Potential" sheet and views a document against the literature in its field and the current level of knowledge and technology; in this sense, particularly, the quality of a document continually varies — changing in profile and usually, but not necessarily, declining in terms of usefulness with the passage of time.

These three viewpoints may be paraphrased as follows:

"QUALITY":
(1) Fit to user: "Just what I want!"
(2) Good workmanship: "Beautifully done!"
(3) Stimulation potential: "Basic!" "Challenging!" "Far-reaching!"

SHEET 1. SURVEY

1. General Nature of Primary Contribu-tion(s):	Properties of Substances	Methods Techniques	Equipment Apparatus	Perform-ance, Test, Functional Evaluation	Inference, Theory	Hypothesis, Conjecture, Speculation	Review or Summary	Report, Announce-ment, News
2. Appar-ent Breadth of Sci-entific Rele-vance:	Narrow, Explicit		Relevance Beyond Explicit Field of Inquiry					
	Single Task or Problem	Same General Field	Relevance Extends to Other Fields	Very Broad Relevance, Basic, Fundamental				
3. Slant of Interest for Target Reader:	Informational Use		Development - Application				Research	
	(For Interest, News)	Planning (For "Sci-entific In-telligence")	Non-prof. (Technician)	Professional (Design)	(Supervisory)		(Experi-mental)	(Theoret-ical)
4. Tech-nical Level:	Non-technical		Requires Little Specialized Knowledge	Assumes Familiarity with Field	Assumes Highly Specialized Knowledge			
5. Antici-pated Dura-tion of Use-fulness:						Indeterminate	Extended	
	Preliminary, Fragmentary, Inconclusive	Project Incomplete	Findings Tentative, Subject to Modification	Mainly of News Value in a Rapidly Changing Field	Obsolete	Depends on Continuance of Interest in Problem	As Reference for Data	Compre-hensive, Archival, Classic

SHEET 2. QUALITY AS ADEQUACY

		Deficient	Adequate	Superior
CONTENT	6. Advance over Previous Publications, Including Those of Author*			
	7. Conclusions and Recommendations Adequately Supported or Qualified			
	8. Documentation (References if Appropriate)			
	9. OVERALL:			
PRESENTATION	10. Descriptive Title			
	11. Informative Abstract			
	12. Adequate Introductory Statement of Problem			
	13. Organization, with Appropriate Headings			
	14. Language Use: Communicative and Clear			
	15. Conciseness			
	16. Illustrations, Charts, Graphs, if Appropriate			

*List other publications, previous or planned, of this work:

SHEET 3. QUALITY AS STIMULATION POTENTIAL
Profile of Creative Contribution

Here we try to identify those aspects of a document by which it participates in the advance of knowledge and technology, those aspects by which it is likely to influence subsequent thought and work.

NO: Need have no derogatory connotation; it simply tells what the document is not.

YES: Identifies without intended commendation the areas of advance establishing a new take-off point for future work and thought.

CONSIDERABLE: Indicates sufficient advance to give a new direction to future research and development efforts.

GREAT: indicates, in addition to the above, a leap of illumined insight or understanding, "more than a solution which would have been easily or ordinarily reached by a competent individual acquainted with all of the previously published material in the field..."

MAGNITUDE OF ADVANCE

	NO	YES	CONSIDERABLE	GREAT
17. New Observations, New Data				
18. New Techniques, Methods, Equipment				
19. Contradiction or Amendment to Earlier Work				
20. New Analysis or Organization of a Problem				
21. Basic Principle or New Theoretical Formulation				
22. Stimulating Question, Conjecture or Hypothesis				
23. Critical and/or Comprehensive Review				

SHEET 4. IMPLICATIONS FOR THE INFORMATION SYSTEM

1. A cross-plot of Item 2 on Sheet 1 and the greatest magnitude of advance indicated on Sheet 3:

24. BREADTH OF APPLICABILITY

4 Very broad Relevance

3 Relevance extends to other fields

2 Relevance limited to same general field

1 Narrow Relevance, limited to specific task or problem

0 No | 1 Yes | 2 Considerable | 3 Great

25. (GREATEST) MAGNITUDE OF ADVANCE

2. 26. TAG FOR SPECIAL CONSIDERATION:

- ☐ Of no use; do not process further.
- ☐ Early review for retirement.
- ☐ Tag for incorporation of results in an appropriate handbook, manual, data table, compendium of methods or equipment, or the like.
- ☐ Disseminate entire document rather than an abstract.
- ☐ Index for extended relevance.
- ☐ Tag for special review or announcement in abstract journal stressing significance and/or relevance.
- ☐ Tag as candidate for inclusion or discussion in a state-of-the-art monograph.
- ☐ Indicate commencement of a citations record.
- ☐ Express processing.
- ☐ Refer to specialist for rating.
- ☐ Other:
- ☐ No special consideration.

SURVEY

In the "Survey" sheet attention is drawn to the following aspects of a document:

a. The general nature of the most important contribution — generally the area of creativeness or innovation.

b. Its breadth of applicability, its generalizability.

c. The interest slant in terms of professional role.

d. The general technical level.

e. Anticipated duration of usefulness, if clues exist based on the nature of its content.

The underlying hypotheses are that these concepts do, in fact correspond to screening factors used by individuals (according to their interests, abilities and professional role), and that they do imply recognizable attributes of a document. Two additional requirements were imposed: that they represent concepts susceptible of being applied to scientific and technical documents, and that they be sufficiently gross that for this preliminary investigation detailed definition and explication should not be required.

a. Nature of Contribution describes by broad categories the main aspect of content for which the document seems likely to be used — often the areas of innovation or the aspects of widest relevance. The list of categories, though adequate for our experimental library of exotic fuel documents, would have to be expanded to encompass the full range of documents in the NASA information system.

b. Breadth of Relevance draws attention to whether the document has scientific or technological relevance beyond its explicit subject matter. A document may be important in a narrow field, and yet not have relevance beyond this; a user's willingness to receive documents may be limited to those of specific subject relevance.

It may be, however, that some aspect of a document appears susceptible of modification or generalization for application in another field; similarly, a user may be willing to consider a wider group of documents, less narrowly specified, in the hope of discovering material which can be adapted to his interests. Some documents have possible relevance in many fields (which can be based on any of the categories of Nature of Contribution). It is recommended that the subject fields be defined as those for indexing the abstract journal.

c. In Slant of Interest for Target Reader the rater is asked to classify the document as to whether it would best serve the needs of:

(1) Those not actively working in the field, but seeking information about it.

(2) Those engaged in development—applying what is known to problems dictated by considerations external to the investigation.

(3) Those engaged in research, for whom application of findings is secondary, and for whom the literature may make its best contribution as a stimulant and aid to conceptualization.

d. Technical Level has to do with the presumed education and technical knowledge of the user. If a reader lacks the knowledge or experience to understand a document, it will not be of high "quality" for his use, however relevant. On the other hand, even highly competent individuals may choose to be introduced to a new field on a relatively nontechnical level. The interpretation of the various levels will vary with the field and the kind of personnel working in it.

e. Anticipated Duration of Usefulness: The utility of some documents is limited to the organization and articulation required in their preparation. This is often true of required progress reports on uncompleted projects. Documents may be preliminary, fragmentary or inconclusive, hence mainly of interest to those currently working on the same problem. They may have news value primarily, serving to announce who is working on what, or to report developments in a rapidly changing field, soon to be relegated to status as a historical record by future "current" developments.

On the other hand, some documents by their nature would be expected to have extended usefulness. This would be true, for example, of compilations of data on properties of substances, scholarly reviews, monographs, fundamental theoretical treatises, etc.

Between these lie completed reports about whose timeliness there is no compelling basis for prediction.

QUALITY AS ADEQUACY

The "Quality as Adequacy" form focuses on aspects of a document for which there are generally accepted standards for publication: newness of contribution, justification of conclusions, adequacy of presentation. However, the highest rating on all of the aspects listed would not necessarily add up to a nontrivial document, judged excellent from other frames of reference. These aspects of a document may assume importance mainly when they are deficient.

QUALITY AS STIMULATION POTENTIAL

In the third form, "Quality as Stimulation Potential," the interpretation of quality comes closest to the usual intuitive interpretation. It views a document against the background of literature in its field and the current level of knowledge and technology. Newness, basicness and insight are the hallmarks of quality in this frame of reference.

In general, a problem which can be resolved by looking through the literature and finding the right "recipe" will be trivial from the point of view of research, although for the purposes of application such problems are far from trivial. For example, one may order by roughly increasing levels of creativity required of the user some of the kinds of scientific or technical problems to which a document may contribute:

To find a specific solution to a problem.

To find material which may be adapted to a given problem.

To structure a problem, determining relevant principles and a method of procedure.

To derive new generalizations, new theoretical concepts.

It is impossible to foresee in what connection a document will be used, but it is generally possible to identify the significant areas of advance and the general nature of the creative contribution.

The categories listed repeat in part those listed under General Nature of Contribution on the "Survey" sheet, but are limited to those aspects of a document by which it contributes to the advance of knowledge and technology, by which it is likely to influence subsequent thought and work on various creative levels. Many kinds of purposes, many levels of achievement are represented among users of NASA documents, and the various aspects of documents listed on this form vary with respect to degree of abstractness and the degree of participation required of the user in order to exploit the document.

IMPLICATIONS FOR THE INFORMATION SYSTEM

Implications of this analysis in terms of specific directives to the information system are summarized on Sheet 4.

It is assumed that a document of high importance in a narrow field is most likely to reach those most interested through request or selective dissemination on the basis of subject identification or direct personal communication with others working on the problem. Documents of broad or indirect relevance are less likely to reach those users who are potentially interested. The function of "browsing" is probably least well served by traditional subject classification. For certain users the general creative level of material may be more important that its subject matter; they may well be the most creative members of the scientific-technical community. This is the very group whose wide scope of interest in terms of traditional subject indexing can invite a deluge of printed matter, and who would profit most by early identification of the most important and seminal documents.

One indication of the kind of initiative the information system might take on first receipt of a rated document derives from plotting the (greatest) magnitude of advance (Sheet 3) against the breadth of applicability (Sheet 1). If relevance is narrow, a high magnitude of advance suggests the desirability of sending the entire document to those working on the same problem. If wide relevance is attributed to a document, as well as high magnitude of advance, then special announcement and review of the document may be indicated. It is recommended that a special section in the abstract journal be devoted to announcing and reviewing such documents, emphasizing possible applications and extended relevance. For processing purposes, identification of documents to be reviewed for special consideration might be given a numerical basis by assigning numerical values to the ratings and computing a score as the product of the ratings on the two axes. Assuming the values shown, the threshold for consideration for special announcement or dissemination might be set, for example, at greater than 5.

Various special courses of action implied by the document analysis are listed as directives to the information system:

Do not process further: there is no significant content, as of a preliminary required report, or one whose content had already been adequately reported or superseded.

Consider abstracted content for republication: tag for possible incorporation of content in an appropriate handbook, manual, data table, compendium of methods or equipment, or the like.

Disseminate entire document: abstract alone would not be indicative or helpful.

Index for extended relevance: explicit clues for indexing in in the document are not sufficient.

Publish special review or announcement in abstract journal: appropriate for documents of wide relevance, of potential interest across the subject fields of concern to the NASA community. Extended relevance and possible applications should be stressed.

Include or discuss in a state-of-the-art monograph: tag to consider for inclusion in a monograph what appear to be important new developments in a field.

Commence citations net: This would permit systematic compilation of future references to the document. Even if citation indexing were not immediately attempted on a comprehensive scale, it could be applied to selected documents. This might be done on a small scale by printing on all distributed copies of the document a notification of commencement of a citation record and request for notification to the information system of future references to the document. This would quickly reveal groups of workers with some overlap of interest, facilitate making them known to each other, and might suggest future re-indexing of an important document on the basis of demonstrated relevance unfolding in time.

Tag for express processing: indicated for documents in fields of extremely rapid development, or when the document served to break a known bottleneck in information.

Refer to specialist for rating: would indicate that evaluation of the document required more knowledge than the rater had and that it appeared to merit referral to someone competent in the field of the document or its possible field of relevance.

The Raters. Since the purpose of quality identification in the information system is to explore the scope and limitations of usefulness of the document rather than to praise or condemn it, for the vast majority of documents their authors will be particularly well qualified to fill out the Quality Profile, especially Sheets 1 and 3 and the note on the bottom of Sheet 2. It is recommended that insofar as possible, rating forms shall be filled out by authors and shall accompany reports submitted to the information system. There seems to be no good reason why the entire form should not be given to the authors. Hopefully, it might result in their becoming more aware of aspects of importance to subsequent users of a document. It is also recommended that authors be requested to include a listing of persons, groups, or fields of interest for which they believe the document would be valuable.

Within the information system those NASA or contractor personnel qualified to process the document for indexing and abstracting would review the authors' ratings and prepare their own on behalf of NASA, taking into consideration their knowledge of the whole spectrum of users of the information system, routing the document to others who are more qualified reviewers if it seems to be of sufficient merit.

The demands upon the rater in terms of knowledge and imagination vary with the item on the forms and with the document. It is clear that no check list by categories can substitute for knowledge which the rater lacks. However, it is believed possible to minimize the role of intuition and to maximize the efficiency of such knowledge as the rater has by systematically developing a quality profile of the document. An important goal would be to identify documents which should be referred for evaluation to more highly qualified readers. The price of filling out these forms is low in terms of time and effort, and it appears that processing could be easily mechanized.

Use of the Quality Profile. A number of the items on the quality profile are time-dependent. Unless the quality profiles are updated they will give an erroneous picture after a lapse of time in which there was further significant work in the field. If the system does not take this into account the most important use of the Quality Profile will be at the time of initial processing by the information system.

Processing at the time of receipt of the document by the information system for quality as well as subject content would allow for possible economy in subsequent processing of reports, for extending the indexing to generalizations and abstractions not found in the text of the document, and would allow for selective dissemination on the basis of quality attributes as well as subject content. Hopefully, by tagging candidates for treatment in secondary publications of various kinds, preparation of the latter could be expedited. Commencing a citation record for documents which appeared to be especially significant would facilitate identifying individuals with overlapping fields of interest. It is recommended that selected items from the quality profile be added to the bibliographic information file to serve as annotation to bibliographies.

A technique for testing quality ratings by feedback from users would compare the quality profile of a document prepared by the information system with a comparable rating form tailored for the individual user to be marked and returned for each hard copy disseminated by the information

Rater:
Name: ____________
Organization: ________
Date of Receipt: ______

Document #1234567
Sent from information center 1/2/64

USER'S RATING FORM

Please check the following, if possible within 2 weeks of receiving the document. The tabulated ratings will be used as a basis for modification of procedures in the information system. Additional comments are invited.

Document was received as a result of:

- ☐ Specific request for this document
- ☐ subject area request
- ☐ Standing request
- ☐ Other:

Document was found to be:

☐ IRRELEVANT or outside my scope of interest

☐ RELEVANT or of interest

- ☐ USEFUL ☐ Read carefully ☐ Read small part ☐ Scanned only
  - ☐ Entire document
  - ☐ Only part of document
    - ☐ Major part ☐ Small part ☐ Bibliography only
  - ☐ For project or assigned task ☐ For personal interest
    - ☐ Essential for carrying out project
    - ☐ Useful but not essential
    - ☐ Glad to have seen it but it made little difference in the course of work
    - ☐ Barely worth seeing
- ☐ NOT USEFUL
  - ☐ Received too late to be of value
  - ☐ Wrong aspect or emphasis of right general subject
  - ☐ Content already known
  - ☐ Content known to be superseded
  - ☐ Trivial or superficial
  - ☐ Preliminary or inconclusive
  - ☐ Fragmentary or incomplete
  - ☐ Too technical
  - ☐ Too narrow
  - ☐ Too comprehensive
  - ☐ Poor work, seems invalid
  - ☐ Too poorly presented: unclear writing, poor illustrations, etc.
  - ☐ Was not translated or was poorly translated
  - ☐ Inadequate bibliography
  - ☐ Other:

☐ JUST DIDN'T READ

- ☐ "Swamped"—didn't have time.
- ☐ In foreign language
- ☐ Obviously outdated
- ☐ Other:

Date of Completion ____________

system. As a matter of fact, this would appear to be the best way to demonstrate that the burden of quality identification as here understood can be placed on the information system and that it does not have to rest entirely on the users.

4.2.2 Quality From the Viewpoint of the User

From an individual user's viewpoint, the quality of a document is measured by whether or not it is useful or interesting, whether it meets his needs and is appropriate to his level of knowledge. The justification for his judgment, however, can in the aggregate provide statistical data to the information system to serve as a guide to what is important to users, what format of presentation would be desirable, what areas of service are most productive and deserving of increased expenditure, and where modifications are needed.

The first basis for screening a document is usually relevance: Does it bear on the user's problem or fall within his field of interest? If it passes his screening for relevance, still it may or may not be useful. If useful, it is of interest to the information system to know how much of the document was useful and whether the user's interest was attributable to a job-related project or to his personal interest, and if job-related, then how vital the information was to the project.

If the document is not useful, the reasons may be varied, but many of them are correlates of items on the information system quality rating forms. Comparing the quality profiles and user rating forms allows for evaluating both forms and the performance of the raters, and for modifying them.

4.3 EXPERIMENTAL TEST OF QUALITY IDENTIFICATION

The Quality Profile was tested by applying it to ASTIA documents on various aspects of rocket fuels. The raters, who were chemists working in the field of exotic fuels, were asked to respond on behalf of the information system rather than as users on their own behalf. Preliminary drafts of these forms were used by five raters on one group of ten documents and by four other raters on another group of ten documents.

The criticisms and suggestions stemming from these efforts, along with considerable clarification of concepts, were incorporated in the forms used in a second very careful analysis of five of the documents by four raters. The purpose was to determine if the concepts were meaningful and applicable to this kind of technical document, and to get some idea of the concurrence of opinion.

The forms comprised 27 items. For the five documents a total of 556 responses were indicated. Instances of agreement were 156 or 28 percent among all four raters, 180 or 32 percent occurred as agreements among three of the raters, 114 or 21 percent were occasions of agreement between two of the raters, and 106 or 19 percent were choices of a single rater. That is to say, 60 percent of the responses were instances of agreement between three or four of the raters. Discussion of the results with the raters indicated that frequently their disagreements could be traced to differences in interpretation of the terse telegraphic terms which had been tailored to fit the space available in the rating forms. Apparently a separate definition sheet allowing for fuller definition of these terms, coupled with an explicit rationale for correlating responses on the Quality Profile with implications for the information system, would have greatly improved communication with the raters and resulted in considerably greater agreement.

It seemed wise to defer further experimentation until research could be undertaken using feedback from a statistically significant number of users.

4.4 CONCLUSIONS

a. Judging quality on behalf of the information system involves exploring the factors beyond subject relevance which contribute to the usefulness of documents for various kinds of users.

b. From the viewpoint of the information system quality may be regarded as:

(1) A relation to the frontier of knowledge and technology.
(2) A relation to accepted standards for publication.
(3) A relation to the user's needs, interests, and abilities.

c. The information in a quality profile, as developed in this study, will allow for more critical discrimination in the processing and dissemination of a document, and will expedite preparation of secondary publications to make selected content available in a form more convenient and assimilable than in the original document. Selected items from the quality profile can be used to annotate bibliographies prepared by the information system.

d. From the viewpoint of the user the quality of a document is a kind of relation to his own needs and interests, and may be expressed as a value judgment... Many of the possible reasons for a user's judgment of quality are correlates of items in the quality profile for the information system.

e. In a small scale experiment in which four individuals rated five documents on the quality profile forms, 60 percent of the responses were instances of agreement between three or four of the raters. Discussion with the raters of reasons for disagreement revealed that they often lay in the lack of explication and definition of the terms on the forms.

4.5 RECOMMENDATIONS

For further study:

a. That in a further study involving a group of 50 to 100 active users and writers of NASA documents, quality profiles and user ratings of the same documents be matched to:

(1) Improve the two forms.

(2) Explore further the factors which determine the usefulness of documents to users.

(3) Determine the requirements for personnel preparing the quality profiles on behalf of the information system.

(4) Explore the usefulness of author-prepared quality profiles and scope-of-interest notes.

b. That a study be conducted to explore use of the "Quality as Adequacy" sheet of the Quality Profile as a means of providing feedback to authors on the quality of their writing and preparation.

Recommendations for the operating information system, provided that the above proposed studies are carried out:

1. <u>Acquisitions</u>

a. That insofar as possible quality profiles and scope-of-interest notes be prepared by authors of documents to accompany the documents when submitted to the NASA information system.

2. <u>Processing</u>

a. That the preparation of a quality profile be included in the routine processing of documents.

b. That selected data from the quality profile be added to the stored bibliographic information for a document, to serve as annotation.

c. That the information system consider using the quality profile as a tool for segregating documents expected to have limited duration of usefulness in order to retire them automatically from search and retrieval except upon specific request.

3. <u>Publication of the announcement abstract journal</u>

a. That a special section in the Abstract Journal be devoted to announcing and reviewing documents rated as of high stimulation ability and wide relevance.

4. <u>Dissemination</u>

a. That the quality profile be used as a tool to screen and select documents which should be sent out, in abstract or in hard copy, on the initiative of the information system.

b. That selected data from the quality profile be stored with bibliographic information on a document, and so be included in request bibliographies as annotation.

5. <u>Response to individual request</u>

a. That the content of the quality profile be used as a guide in selecting among relevant documents in order that they should correspond as closely as possible to the special characteristics of the user and the problem situation.

6. <u>Arrangement for secondary publications</u>

a. That the quality profile be used as a tool to expedite selection of information and documents for "repackaging."

5. FRAGMENT RETRIEVAL STUDY

5.1 INTRODUCTORY REMARKS

The study presented in this section and the Information Correlation Study of Section 6 are both addressed to the problem of assimilability of the output for the user of a technical information system.

In these studies we consider two rather specific types of information usage. The first is to answer questions and check hypotheses or conjectures; the second is to form new hypotheses or conjectures. The Fragment Retrieval Study of this section attacks the problem of how to reduce the amount of system output without loss of essential content so as to make it more efficient for the first usage. The Information Correlation Study gives an approach to the analogous problem for the second usage. In either case, it is to be noted, the emphasis is not on the two classical information retrieval problems of (1) not retrieving relevant (2) retrieving irrelevant; but rather on the new question of how to modify or structure the output obtained.

5.2 THE PROBLEM OF RETRIEVAL OUTPUT

One of the difficulties facing the users of tomorrow's information systems is the likelihood of being presented with their own personal information problem in the form of overgenerous responses to requests for information. Even in cases where all retrieved material is in some way relevant to the particular request, the user is still left with the chore of wading through a large or small pile of documents to locate the information he requested.

Although a user may sometimes prefer to see all relevant material, most of the time he would probably be quite happy not to. Even the occasional person who has the leisure to be compulsive about seeing all material related to his own research would probably enjoy being relieved of the obligation of scanning whole documents to keep informed of developments in his field. If a portion of a document can satisfy a request for information, there would seem to be little incentive to peruse the entire document and less to read through a stack of additional documents, relevant or not. On this assumption, an experiment was designed to test whether certain types of requests for information can in fact be satisfied by portions or fragments of documents; and if the assumption proved valid, of what size the fragments should be.

5.3 EXPERIMENTAL DESIGN

It was felt that the fragment to be used in the study should conform to the following requirements: (1) they should comprise natural units of information, e.g., sentences, paragraphs; (2) they should be composed and selected by mechanizable criteria.

Four types of document fragments were created for this purpose, using a sample of 60 documents from the experimental library on exotic fuels. The first type of fragment is a machine-produced document extract, which represents about 25% of the total material contained in the document. Another type of fragment is a paragraph characterized by a dense cluster of search terms. The sentences of the machine extract, taken individually, constitute a third type of fragment, while the individual sentences of the entire document represent a fourth fragment type. (Examples of these types of fragments are given in Appendix A6.)

As an initial step in the experimental procedure, retrieval questions were formulated by our consultants for this project, who were experts in the field of advanced propellants. As a compromise between introducing bias by allowing direct inspection of the document, and risking nonintersection of information requested with the contents of the library by allowing the formulation of random questions, the consultants were permitted to base their questions upon the ASTIA abstract cards for the experimental library. Any type of question was permissible—the only requirement was a reasonable amount of confidence that the answers to such questions could be found in the sample library. The consultants were also asked to expand content terms (words and phrases) of their questions by adding synonymous concepts, thus creating thesaurus-type word groups to aid in the retrieval. These word groups were further expanded by the addition of inflected forms (plurals, the various tenses, and so forth) for all words. A list of the retrieval questions with the original word groups (that is, before the addition of inflected forms) is attached as Appendix A1.

In addition to expanding key terms, recasting the questions into search prescriptions involved a further step: the definition of prime versus secondary terms. Most questions proved to contain one term which singled out an area of interest plus one or more terms restricting the latitude of that area. In question 1, for example, the requester's main concern is to obtain information on the coefficient of viscosity, but he wants this information only for mixtures whose primary constituents are ammonia and hydrazine. Thus the primary or "A" term is "coefficient of viscosity" and the secondary or "B" terms are "mixtures," "ammonia" and "hydrazine."

These terms were defined for each question and specified for retrieval according to the following rules:

Documents Extracts Paragraphs*	must contain all terms
Sentences	must contain the A term or n B terms, where n is given by the table:

n	number of B terms
1	1
2	1
3	2
4	2
5	3

*At least 2 paragraphs must be retrieved for each document. In cases where no paragraphs satisfy the above requirements for retrieval, the two most responsive paragraphs will be selected in text order.

Specifications for retrieval of sentences and in certain cases, of paragraphs, are less strict than those for documents and extracts, as the probability that a smaller segment of text will contain all terms is considerably less than for the large segments.

An objection might be raised as to the legitimacy of the distinction between A and B terms, for it seems to assume that information on the coefficient of viscosity for mixtures of hydrazine and allyl alcohol would be more responsive to question 1 than information on some other rocket performance parameter for ammonia and hydrazine mixtures; whereas both responses are clearly (and for all practical purposes, equally) irrelevant.

What is important here is not the logic of the A/B distinction, but how this distinction was actually used in the retrieval procedure. An examination of the retrieval rules indicates that the distinction operates only for the smaller segments of text—that is, sentences, and in some cases, paragraphs. If the sentences of the entire library were individually tested for responsiveness to a question, the situation described above might reasonably be expected to occur, and the objection raised would be a legitimate one. (If a retrieval system were to operate in this way, the user should be at least allowed to select the A term.) This argument is invalid for our retrieval experiments, however, as individual sentences of a document were tested for relevance to a question only after the document itself had been determined to be responsive as defined by the retrieval rule for documents, which requires that all terms be present. This was consistent with our objective in designing the experiments, which were intended as a test of document versus fragment retrieval rather than of a particular retrieval system.

5.4 EXPERIMENTAL PROCEDURE

Although the retrieval was performed manually to avoid the time investment required for programming and checkout, the retrieval procedure could easily be automated. The basic retrieval tool was a set of 3 machine-produced concordances prepared for the 60 documents upon which retrieval questions were based. These concordances list document, paragraph, and sentence numbers for each occurrence of each word; a sample concordance page is attached as Appendix A2. Those documents, extracts, paragraphs, and sentences which satisfied the retrieval requirements were listed as shown in Appendix A3. For 9 of the original 41 questions, no relevant material could be found in the sample library. An example of this was question 38: "Is dinitrotoluene used in solid propellants?" which failed because the library contained no documents relating to dinitrotoluene.

As a first step in preparation of the retrieval results for evaluation by the consultants, the fragment types were given the following designations for each question.

A: Set of retrieved machine extract sentences;

B: Set of retrieved document sentences;

C: Set of retrieved document paragraphs;

D: Set of retrieved machine extracts.

The average number of sentences per type is as follows:

A	B	C	D
7	16	10	26

All types of fragments were not always retrieved for every question.

Typed sheets were then prepared for each fragment set, and the sets were ordered for each question in terms of relative size, the smallest being labeled level 1, the next smallest, level 2, and so forth. Type A fragments were generally the smallest, being assigned to level 1 in 34 out of 57 cases. Type D fragments were found to be the largest in 24 out of 35 cases. Statistics for the distribution of fragment types per numerical level are given below:

Size Level	Fragment Types A	B	C	D
1	34	7	16	0
2	17	9	24	2
3	0	30	7	11
4	0	10	1	24

For questions having more than one answer document, the size levels were individually computed for each document so that there were potentially two or more fragment sets for each numerical level.

A rating form (Appendix A5) was then designed to facilitate evaluation of retrieval results by the consultants. For each of the five numerical levels (level 5 being the document(s) from which the fragments presented on the other levels were extracted), a decision was required as to whether the information contained in that level was

a. irrelevant to the question; or
b. constituted a partial answer to the question; or
c. formed a base from which the answer could be inferred; or
d. constituted a complete answer to the question.

For questions having more than one answer document, we required an additional evaluation based on the cumulative evidence of all fragment sets for each particular level. Thus, for a question having 2 answer documents, 3 rating forms were attached—two for independent evaluations of each numerical level of each of the two documents and a third for a cumulative evaluation of both documents.

For each question, the consultants were also asked to indicate by single and double underlines, respectively, material in the body of the documents which was (1) relevant to the question, and (2) constituted a minimal complete answer. A copy of the instructions for evaluating retrieval results is attached as Appendix A4. A sample question and answer set is included as Appendix A6.

5.5 RESULTS OF EVALUATION

Of the 32 questions presented to the consultants for evaluation, 21 were judged to have received a complete answer. Appendix A7 gives a detailed explanation of why retrieval sets failed to satisfy the questioner's requirements for each of the 11 retrievals which was judged incomplete. Of the 21 questions which received complete answers, 19 were found to have been answered completely before the fourth numerical level was reached— 10 having been answered on the first level, 5 on the second, and 4 on the third. One additional question was answered on the fourth level; the remaining two required the full document. The average size of fragment sets on the first level was 7 sentences, on the first two levels: 9 sentences, on the first three levels: 12 sentences. That is to say, of all the questions receiving complete answers, 90% were answered within an average of 12 sentences (about 16% of the document). These figures seem to present a convincing argument for fragment retrieval as against document retrieval, at least for the types of questions used in these experiments.

Results of cumulative evaluations of numerical levels for questions having more than one answer document were rather disappointing, in that the cumulations were not judged to contain any more information than the separate elements making them up.

A study of the distribution of fragment types among the answer classifications: "complete answer," "answer can be inferred," "partial answer," "irrelevant," provides a measure of the effectiveness of each type of fragment in answering questions. To evaluate this data it is convenient to examine the distributions relative to the information content of the complete document. We can then ask: what is the probability of a given fragment type containing as much information as the full document, less information than the full document (but some relevant information), being irrelevant when the full document contains information, not being retrieved when the full document is retrieved? These probabilities (computed by relative frequencies) are shown in the table below. (Tables for the individual answer classifications are presented in Appendix A-8.)

Fragment Type	Classification			
	Contains as much Information as Document	Contains Information but less than Document	Irrelevant	Not retrieved
A (Extract Sentences)	.46	.13	.33	.08
B (Document Sentences)	.77	.10	.13	0
C (Document Paragraphs)	.56	.15	.21	.08
D (Extracts)	.36	.10	.21	.33

Thus fragment type B dominates in effectiveness, with C, A, and D following in that order. It is to be noted that the lengths of the type D fragments are 25 percent of the full document, which we can compare with the 36 percent probability of containing as much information.

The indication of relevant material and material constituting a complete answer supplied by the consultants for each question can also be used to evaluate the relative retrieval effectiveness of each fragment type versus the document. The procedure is to use the retrieval effectiveness measure described in Section 7. This data is presented in Appendix A-9. The results confirm the probabilistic results given above. An additional statistic of interest is that given by the proportion of retrieved sentences relevant for each fragment (relevance density of fragment). This is shown in the table below.

A	B	C	D	E
.29	.30	.23	.18	.14

5.6 CONCLUSIONS AND RECOMMENDATIONS

a. Conclusions

(1) Within the limits of the experimental framework, the results of our experiments clearly indicate that retrieval of document fragments can fully satisfy some types of information requests.

(2) All four fragment types carry a large proportion of irrelevant material, ranging from .70 for B type fragments to .82 for the D type. These figures do not differ significantly from the .86 content of irrelevant material computed for the documents.

(3) Although these experiments have demonstrated the adequacy of fragment retrieval, a fragment type which could be characterized as "optimal" with respect to the proportion of relevant versus irrelevant material contained did not emerge in the course of our study.

b. Recommendations

(1) It is recommended that several means be investigated to reduce the quantity of irrelevant material retrieved:

(a) One method involves inspecting the form of the question in order to determine what type of answer is appropriate. By associating lists of cue words with particular interrogative forms, this irrelevant retrieval could be controlled.

(b) Much of the irrelevant material may be due to redundancy. One approach to this problem is the use of content analysis techniques to identify sentences which are equivalent in content, thus making it possible to eliminate one of a pair of essentially synonymous sentences. Other methods for reducing the quantity of irrelevant material should emerge from a comparative evaluation of the content of the various fragment types versus that of the material labeled relevant by users, in relation to the retrieval questions.

(2) It is recommended that the concept of an "optimal" fragment be further studied:

(a) Another interpretation is that of a fragment which the user considers optimal for his particular purposes. An attempt should be made to obtain a judgment as to whether any of the fragment sets or the material labeled relevant by the users themselves would in their opinion constitute an optimal response to the particular question.

(b) The notion of an optimal fragment can be extended to the announcement function and tied in with a system for selective dissemination of newly acquired material. By combining a weighted list of concepts of interest to a particular user, with an automatic abstracting program, extracts of new material can be produced which will be specifically tailored to the user's interests but at the same time will retain enough of the structure of the original document to orient the user's specific interest to the author's main thesis.

(3) It is recommended that the adequacy of fragments to answer more subtle types of questions be investigated. Some interesting experimental results can be obtained by transforming human inferences for correlation experiments into retrieval questions for additional experiments in fragment retrieval. This would test the adequacy of fragments to answer more subtle questions while simultaneously providing a scale of evaluation for the inferences, since it can be assumed that retrievals for questions based on inferences synthesizing information explicitly stated are more successful than those based on implicit inferences.

6. INFORMATION CORRELATION STUDY

6.1 INTRODUCTORY REMARKS

Another aspect of the information problem is the effect of information loads of varying sizes upon the user's ability to assimilate and correlate data. It seems plausible to assume that the user's ability to correlate information is a function of the volume of information to be assimilated; and moreover, that this ability will improve with increasing volume until a certain critical volume is reached, beyond which the load of information causes the user's correlation ability to deteriorate rapidly. This assumption gives rise to two fundamental questions:

1. what is this critical volume in a given situation?
2. is it possible to structure information in some way so as to improve the user's ability to assimilate and correlate, thus extending the critical limit?

An experiment performed in connection with an earlier project on information retrieval and correlation provided some interesting preliminary answers to these questions.

The library for this series of experiments consisted of a simulated intelligence file of fragments developed from a book—"Kogun - the History of the Japanese Army in the Pacific." A machine-produced concordance of all words contained in the fragments served as an index to the file.

The experiment of particular significance here is one which dealt specifically with the time dimension. All fragments containing any reference to time of day (for example, "noon," "0645," "dawn," "8:00 a.m.") were retrieved. About 25 fragment cards were retrieved in all. The fragments of this set had at least two attributes in common: they concerned the Pacific War in some way, and contained some reference to time of day.

The randomly ordered cards were presented to several persons, who noticed only that all cards referred to battles in the Pacific War.

When the cards were reordered into two groups of night versus day, however, a striking correlation emerged—namely, that all daylight attacks had been initiated by U.S. forces and all night attacks by the Japanese. (This correct inference, incidentally, was nowhere explicitly stated in the book.)

The results of this experiment suggest that the critical volume of information may in fact be extremely small. Only 25 cards were involved, and each card contained a single fragment, which in this case was a minimal piece of information. Moreover, these fragments had certain attributes in common—"Pacific War" and "time of day." The correlation described above, however, was not discovered until the set of fragments was structured in terms of conceptual subgroups—"night," "day"—included in the semantic range represented by "time of day."

These findings suggest that structuring of data can extend the critical limit on volume, and further, that the elements of this structure should be subsets consisting of closely related members of the main set. The results of the earlier experiment thus established a point of departure for the present investigation.

6.2 EXPERIMENTAL DESIGN

A considerably more complex series of experiments was designed to test whether the "Kogun" discoveries provided essentially correct answers to the two questions raised above. We decided to create a set of data structured along the lines described above—that is, a set whose structure is based on subsets consisting of closely related members of the main set. A second set of data more loosely structured than the first would be provided by the main set itself. A third set would consist of unstructured data compiled randomly. The ability to assimilate and correlate the information presented in these variously structured sets of data would then be tested by requiring our consultants to list inferences suggested by each set. Based on the "Kogun" experiment, it was assumed that the first set of data, being the most highly structured, and therefore, most easily assimilated, would be most productive of inferences; and the random data, least productive.

The type of structure represented by the first set of data is most conveniently generated by "clustering" techniques.* The object is to cluster the data in natural groupings whose members are associated through co-occurrence of concepts. The procedure is as follows: if two items of the data set have a concept in common they are said to be associated. A cluster is then defined as a collection of items which are mutually associated as well as being maximal with respect to this property. This last condition means that an item cannot be added to the collection without violating the property of mutual association. The definition of association can be strengthened by stipulating that several concepts must occur in common. The technique used is a mathematical procedure for exhaustively listing these clusters.

6.3 EXPERIMENTAL PROCEDURE

Materials to be used for the creation of the three data sets were a fragment file of document and abstract sentences which were generated as a by-product of the fragment retrieval experiments, and the set of three machine-produced concordances, which served as an index to the file.

The first step in the experimental procedure consisted of selecting a single fragment called the F_1 fragment, which would serve as the nucleus for a "star" containing all fragments related to the F_1 fragment through co-occurrence of concepts. This is diagrammed in Figure 4. The lines between fragments indicate the co-occurrence of concepts; for example, if F_1 contains the words "small motors" and F_2 contains the word "micro-burner" then the same concept can be said to occur. Clusters of fragments associated by co-occurrence of concepts in addition to the F_1 defining concepts can then be derived from the F_1 star.

*"Word Correlation and Automatic Indexing," Progress Report No. 2, 21 December 1959 (C82-0U1).

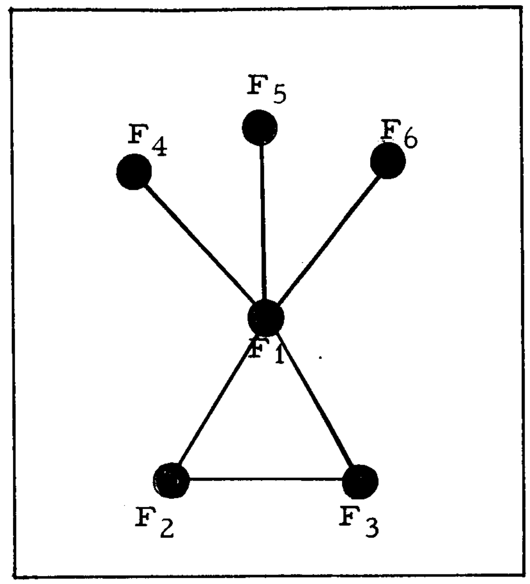

Figure 4. Illustration of F_1-star

As an illustration, in Figure 4 the set $\{F_1, F_2, F_3\}$ is a cluster, so are $\{F_1, F_4\}$, $\{F_1, F_5\}$, $\{F_1, F_6\}$. These clusters can serve as the maximally structured set of data for the experiments, while the members of the F_1 star would constitute the loosely structured set.

Since the magnitude of the task of developing these structures manually is directly proportional to the number of fragments involved, it is essential that the membership of the star should not be too large. On the other hand, if its membership is too restricted, the star will not contain enough information for valid generalizations to be made. As the membership of the F_1 star depends on the number of concepts contained in the F_1 fragment and their distribution throughout the fragment file, it can be seen that selection of the F_1 fragment is the crucial step in the experimental procedure.

Attempts to limit the size of such stars by arbitrarily restricting the number of fragments taken from each document proved unsuccessful, as did several other artificial means of coping with an oversupply of related fragments. Many potential F_1 fragments were selected, found inappropriate, and rejected before the following F_1 fragment was chosen:

"Space mission studies have indicated the need for small rocket motors of low thrust (of the order of 100 lb) for attitude control, midcourse trajectory corrections, rendezvous, and so forth."

Concepts used to define the F_1 star were as follows:

small	and	motors burners engines	or	micro	and	motors burners engines

space

trajectory

control and attitude

rendezvous

All cards containing these concepts were then retrieved from the file. There were 24 in all, yielding an F_1 star of 24 members (Appendix B1), which proved to be a workable amount.

A list of concepts was then developed for each of these fragments (Appendix B2) and the list for each fragment was compared with that of all other fragments in the F_1 star to determine which fragments had the greatest number of concepts in common. A correlation matrix was created in which fragments having two or more concepts in common were labeled as strongly correlated, those having only one common concept as weakly correlated. "Strong" and "weak" clusters were then derived from the matrix by a mathematical technique described in Reference 1. (Lists of strong and weak clusters are contained in Appendix B3.)

At this point it became apparent that the manipulations of data necessary to generate a maximally structured set of fragments and prepare the test materials for the consultants were proving so time consuming as to make the execution of our original experimental design an unrealistic objective. We therefore decided to abandon the idea of creating three separate sets of data for the present and concentrate our efforts on gathering as much information as possible on the maximally structured set of data, which was nearly complete.

Since the intent of our original experimental design was to test the user's ability to assimilate and correlate information having various degrees of structure, it was still possible to implement this design on a very refined level within the maximally structured set of data; for a greater degree of relatedness or structure is required by the defining criteria for strong versus weak clusters. It was therefore expected that inferences derived from strong clusters would exhibit some distinctive property as compared to weak clusters.

A further test of assimilation and correlation ability could be achieved by imbedding the clusters in successively larger segments of text, on the theory that correlations obvious in the clusters as represented by the fragment cards would be obscured if the clusters were instead represented by the documents from which they were culled. We therefore selected 12 clusters—6 strong and 6 weak—which were represented by four levels of material:

Level	Description
D	Cluster is represented by the fragment cards.
C	Cluster is represented by the sentence on the fragment card plus the six sentences (3 preceding, 3 following) which form its immediate context within the document.
B	Cluster is represented by the machine-produced extract of the document.
A	Cluster is represented by the document itself.

The clusters were then divided into four groups of three clusters each. The material for level A of the first group of clusters was placed in a folder marked for the first consultant along with the level B material for the second group of clusters, the level C material for the third, and the level D material for the fourth, so that none of the four consultants would have the opportunity to draw inferences from the same cluster on two levels. These elaborate precautions were to prevent the consultants from becoming familiar with the same cluster through its representations on various levels, causing a tendency to make the same inference for the different levels rather than looking for new correlations which might be exposed in proceeding to a level where the cluster is less deeply imbedded in peripheral material. The consultants were instructed to begin with level A and proceed to level D, observing the time limits imposed for reading the material and making inferences. (A copy of these instructions is attached as Appendix B4.)

6.4 RESULTS

A total of 152 inferences were listed by the consultants. (The inferences listed by Participant II and the clusters from which his D-level inferences were derived are contained in Appendix B5; inferences derived on all four levels for cluster S-16 are contained in Appendix B6.) Of these, exactly half were derived from strong clusters and half from weak. The level from which the largest number of inferences was derived was the A level, which also contained the most material. 51 inferences were listed for the A level, 42 for the B level, 34 for the C level, and 25 for the D level, indicating a strong correlation between quantity of material and number of inferences produced, which we had intended to offset to some extent by imposing time limits for reading and reference listing. The inferences were then uniquely classified into the following categories (inferences indexed under "Heat Transfer" are listed in Appendix B7):

Propulsion Systems	Combustion Efficiency
Propellant Combinations	Combustion Stability
Propellant Evaluations	Ignition
Reliability	Heat Transfer
Performance	Problem Areas
Design	Extrapolation of Test Results
Chambers	Applications for Small Motors
Storage and Handling	

The inferences derived on the various levels were compared to determine whether the classes of inferences had members from all levels; or whether, as we had postulated, the relations between members of a cluster would be obscured when the cluster was represented by large segments of data, so that the same type of inference could not be derived from all representation of the same cluster. This assumption proved false in the present investigation.* The same types of inference were frequently listed for levels A through D, as shown by the data for strong and weak clusters in Appendix B8.

The original fragment cards making up the clusters were then assigned to as many of the above categories as were applicable in order to compare the extension of the clusters with that of the inferences derived from them. Intersections of categories were plotted for the clusters and for inferences made at the D level—i. e., those derived directly from the clusters themselves. A correlation coefficient was used to determine the degree of "overlap" between clusters and inferences, thus measuring their conceptual closeness. Although the correlation coefficients for both strong and weak clusters were good, inferences derived from strong clusters proved significantly more highly correlated with their parent clusters than did inferences derived from weak clusters. The strong clusters scored .61, the weak ones .43, where the coefficient is on a scale from -1 to +1 with 0 being the point of random correlation.

6.5 CONCLUSIONS AND RECOMMENDATIONS

a. Conclusions

(1) These data support to some extent the hypotheses suggested by the "Kogun" experiments.

(2) The consultants were able to recognize relations between members of a cluster and make inferences based on these relations even when the cluster was represented by large segments of text.

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*Swanson suggested that this could be attributed to the fact that the critical volume was not reached due to the overgenerous time limits.

b. Recommendations

It is recommended that several questions raised by this experiment be further investigated:

(1) Would conclusion two above apply for more loosely structured sets of data--if the 24 members of the F_1 star, for example, were imbedded in successively larger segments of text, would the basic relation still be discernible, or would inferences derived be diffused and general rather than highly correlated with the star from which they were derived?

(2) What sort of inferences would be derived by applying the layering technique to a random selection of fragments related only by coming from literature in the same field?

(3) Another type of question is more thought-provoking, and less readily answerable. It departs from the notion of an inference as a measure of the ability to assimilate and correlate information and considers instead the nature of an inference. We have discussed the correlation between basic data and inferences derived from these data, but is it reasonable to expect such correlation to exist? Perhaps the mark of a good inductive inference is that it exhibits little conceptual relatedness to the data from which it was derived. Again, what is a "good" inference? Should good be interpreted as non-trivial? How much information should be carried in an inference? All these avenues should be explored.

7. SYSTEM EFFECTIVENESS STUDY

7.1 INTRODUCTORY REMARKS—TERMINOLOGY

This study is addressed to the problem of measuring the quality of the product provided to the user by an information system. For this purpose we shall regard an information system as a three-term relation between (1) an input consisting of a user's information requirement, (2) a collection of information "packages" (e.g., documents, abstracts, titles of documents, photographs, tabular data, etc.), and (3) an output consisting of a certain selection of the collection.

It is clear that the "quality of the product" will depend on the time elapsed from input to output; but, within the scope of the present study, time will be omitted as a variable. The exclusion of time as a variable is equivalent to assuming zero access time to the collection and consequently excluding the interaction of the user with the system. Thus we must fix the information requirement of the user at a single instant in time. To do this we equate the information requirement with the communication of the requirement to the system and we assume that this communication is in natural language (as opposed to a "coding" of the requirement in, say, library index terms). This allows us to treat the input and output of the system as entities of the same logical type.

To complete the model, we next assume that there is a referee who can decide for any item in the collection not only whether it is relevant to the statement of information requirement or not, but also decide between any two relevant items whether one is more relevant than another. Furthermore, let us suppose that these comparative evaluations are reflected in a numerical scale of degree of relevance: the most relevant item receiving unity as the degree of relevance, irrelevant items receiving zero as the degree of relevance. Let

ρ_{ij} = degree of relevance of the i^{th} item to the j^{th} information requirement.

Similarly, it is appropriate to regard the selection procedure, which characterizes the information system, as a procedure for assigning numbers to items. (These numbers can be regarded as the system-calculated strength-of-match between collection item and information requirement.) Let

s_{ij} = number assigned by selection procedure to the i^{th} item for the j^{th} information requirement.

This includes as a special case the usual notion of selection procedure if we allow s_{ij} to take on only the values zero (item is unselected) or unity (item is selected). Analogously we call items for which s_{ij} is not zero "selected," items for which s_{ij} is zero "unselected."

To summarize: the model consists of (1) information requirements, j; (2) information "packages," i; (3) a selection function giving a numerical match between i and j, s_{ij}; (4) an evaluation criterion giving the degree of relevance of i for j, ρ_{ij}.

7.2 GENERALITY OF THE MODEL

A hierarchy of operations of an information system has been pointed out in Section 3: ranging from acquisition to specific document retrieval. By varying the definitions of "user," "collection," and "selection procedure" the system discussed in Section 7.1 can be seen to cover each of these operations. For example, if we interpret "user" as an entire class of users covering a rather broad field of interest; interpret "collection" as all currently recorded information in documentary form, and "selection procedure" as the method of acquisition, then the model defines the operation of acquisition.

7.3 THE NOTION OF PERFECT RETRIEVAL

Let us examine the plausibility of obtaining satisfactory evaluation criteria of the form of judgments of values ρ_{ij}. The motivation behind this choice of criteria is the feeling that a "perfect" information system would be one in which an expert in the field of the information requirement of the user makes the selection of the appropriate items by making a direct and exhaustive examination of the entire file (in zero time). Thus, we can regard the condition $s_{ij} = \rho_{ij}$ as a case of perfect retrieval.

Consider first the problem of information retrieval, i.e., the retrieval of documents which have potential value in answering rather specific questions. Experimental results for a small library of documents on nuclear physics have shown that experts (nuclear physicists) could independently and consistently make judgments of the degree of relevance.*

For the problems of compiling bibliographies, dissemination of documents in response to standing requests, and acquisition of documents for a community of users we suppose that appraisals can be made of the responsiveness of each item for each request.**

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*"Word Correlation and Automatic Indexing," Phase I Final Report "An Experiment in Automatic Text Searching," 30 April 1960 (C82-0U4).

Swanson, D.R., "Searching Natural Language Text by Computer," Science, October 21, 1960, vol. 132, no. 3434.

**A discussion on judgments of relevance of items for general fields of interest can be found in: Maron, M.E., Kuhns, J. L., "On Relevance, Probabilistic Indexing and Information Retrieval," J. Assoc. Computing Machinery, vol. 7, no. 3, July 1960.

7.4 DEVELOPMENT OF A MEASURE OF RETRIEVAL EFFECTIVENESS*

In this section we shall develop an effectiveness measure from two points of view. To begin the discussion, we will first suppose that both the perfect retrieval data and the selection criteria are two-valued: items are either "relevant" or "irrelevant," and are either retrieved or not retrieved.

The approach will be to treat this simpler situation, then generalize the results to quantitative data.

Stated in its simplest terms, the problem is to take into account both the proportion of relevant material retrieved and the proportion of retrieved material relevant. That is, suppose there are m relevant items in the collection. System I yields n_1 documents of which x_1 are relevant and $n_1 - x_1$ irrelevant (hence $m - x_1$ relevant items are not retrieved). System II yields a retrieval with numbers in the corresponding categories: n_2, x_2, $n_2 - x_2$, $m - x_2$. Which method is more successful?

To answer this question we look for ways of comparing a result with the perfect retrieval. In the simplified case the collection is sorted into two classifications: a document is either relevant or irrelevant to the user's information need. Similarly the selection procedure itself sorts the collection into two classifications: an item is retrieved or not retrieved. By combining these classifications we arrive at the following partition of the collection:

a. relevant and retrieved,
b. irrelevant and retrieved,
c. relevant and not retrieved,
d. irrelevant and not retrieved.

Let x, u, v, y be the respective cardinalities of these classes and let n be the number of items retrieved, m the number of relevant items,

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*The measure proposed herein was developed under sponsorship of the Council of Library Resources. See "Word Correlation and Automatic Indexing," Progress Report No. 2, App. C, 21 December 1959 (C82-0U1).

t the total number of items in the collection. These quantities are not independent but are bound by the relations:

$$u = n - x, \tag{1}$$

$$v = m - x, \tag{2}$$

$$y = t - x - u - v. \tag{3}$$

Since t and m are fixed (the latter by perfect retrieval) the effectiveness of a given selection procedure is characterized by the variables n and x. The measurement of this effectivness, i. e., the numerical comparison with perfect retrieval, requires then, the specification of the values of a certain function of these variables:

$$f(n, x).$$

This function is not completely arbitrary, but must satisfy certain requirements. First we have:

Requirement 1. Requirements for the Domain

$$0 \leqq x \leqq n \leqq t, \tag{4}$$

$$x \leqq m, \tag{5}$$

$$n + m - t \leqq x. \tag{6}$$

Thus the domain consists of the points having integral coordinates enclosed in the parallelogram with vertices (0, 0), (m, m), (t, m), (t - m, 0). The four vertices are of special interest and are given special names:

N = (0, 0), null retrieval
P = (m, m), perfect retrieval
T = (t, m), total retrieval
W = (t - m, 0), worst retrieval (all irrelevant and no relevant)

The diagonal NT of the parallelogram (Figure 5) is also of interest. This line, given by,

$$x = \frac{m}{t} n \tag{7}$$

is the line of random retrieval, for if x and n are related by (7) then x assumes the expected value of a random retrieval. Other lines of interest are

$$\text{NP:} \quad x = n \tag{8}$$

and

$$\text{PT:} \quad x = m \tag{9}$$

NP (with the exception of N) gives high relevance density in the retrieval; PT gives high coverage of relevant items.

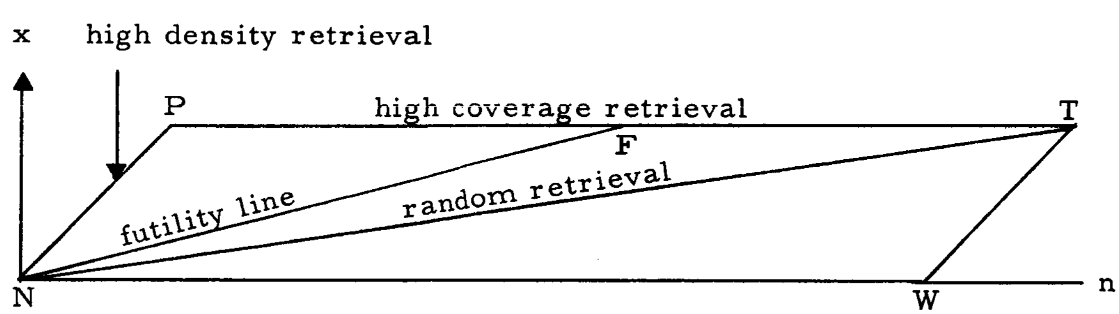

Figure 5. Retrieval Parallelogram

We now look for suitable values to assign to the measure function f(n, x).

Requirement 2. Maximum Value.

f should have a maximum value and this value should be assumed at P. Since the value is arbitrary we take it to be unity.

$$f(m, m) = 1 . \tag{10}$$

Requirement 3. Futile Retrieval.

If n attains a certain value, say k, the retrieval shall be deemed worthless and the f value stipulated to be 0.

The value k is based on the user's personal estimate of the utility of the information required; e.g., suppose the user will accept a list of n documents to obtain all relevant information when $n < k$, but will reject the list when $n > k$. We thus assign a value:

$$f(k, m) = 0 . \tag{11}$$

We call the point (k, m) 'F'. By the same reasoning we get

Requirement 3'. Futility Line

If $x = \frac{m}{k} n$, then $f(n, x) = 0$.

This is because all points on the line NF have the same relevance density as the point F. Note that the extreme case is attained when k goes to t and the futility line and the line of random retrieval coincide.

Requirement 4. Variation of f

In the triangle NPF f should have the behavior:

(1) $f(n, n)$ increases as n increases,
(2) $f(n, x)$ decreases as n increases (for fixed x),
(3) $f(n, x)$ increases as x increases (for fixed n).

We choose the simplest function that satisfies these requirements. This is easily seen to be the plane that passes through the points (0, 0, 0), (m, m, 1), (k, m, 0) in the (n, x, f)-space. Thus we define

$$f(n, x) = \frac{kx - mn}{m(k - m)} \tag{12}$$

Let us now look at the problem from a completely different viewpoint. We will examine a hypothetical situation of system usage and define our measure of retrieval effectiveness to depend on the actual cost to the user of a single search.

Suppose a user A requires certain information to obtain a gain of α dollars. This information is partitioned into m units, each unit corresponding to a (relevant) collection item. Now if A requests this information from the system, the retrieval will be possibly imperfect. In particular, the relevant information not retrieved must be obtained from another source, say at a cost of β dollars per information unit. Let the cost of the retrieved information—relevant or not—be 1 dollar per item. The net gain from the system (independent of the later use of the information) is

$$V = \beta x - n \tag{13}$$

The total net gain is therefore

$$(\alpha - \beta m) + V . \tag{14}$$

We see that it would be immaterial to A if he used the system if $V = 0$ when $x = m$. This situation will arise when

$$n = \beta m .$$

This number βm is the 'k' determining the futility line, i.e.,

$$k = \beta m, \tag{15}$$

and $V = 0$ when $x = \frac{m}{k} n$.

Substituting (15) into (12) we get

$$f(n, x) = \frac{\beta x - n}{m(\beta - 1)} . \tag{16}$$

By (13) we see that the maximum value to be gained from the system is the denominator of (16), namely,

$$V_{max} = m(\beta - 1) \tag{17}$$

Thus $f(n, x)$ has the quite natural meaning:

$$f(n, x) = \frac{V}{V_{max}} = \frac{\text{net gain}}{\text{maximum possible net gain}} \tag{18}$$

It is easy to show that the quantity $1/V_{max}$ can be interpreted as a penalty coefficient for irrelevant retrieval. Let

$$p = 1/V_{max} = 1/m(\beta - 1) \tag{19}$$

then

$$f(n, x) = \frac{x}{m} - p(n - x) \tag{20}$$

Denoting x/m (the proportion of relevant material retrieved) by 'R'; $n - x$ (the amount of irrelevant material retrieved) by 'I', we rewrite $f(n, x)$ in the simple form

$$f(n, x) = R - pI \tag{21}$$

Turning our attention to the more general situation of a perfect retrieval given by the specification of the degree of relevance for each document, let us see how the cost analysis approach works.

Define

$$\rho_i = \text{degree of relevance of the } i^{th} \text{ document} \tag{22}$$

The only requirement we impose on ρ_i is:

$$0 \leqslant \rho_i \leqslant 1 \,. \tag{23}$$

Again, we take β to be the dollar value of the information in an item having the maximum degree of relevance, i.e., the cost of obtaining it from another source. Thus the value to a user if the i^{th} item is retrieved is

$$\beta\rho_i - 1$$

Again, let n be the number of items retrieved and suppose these are the items designated by $i = 1, \ldots, n$. Then, analogous to (13), we have the net gain from using the system

$$V = \sum_{1}^{n} (\beta\rho_i - 1) \,. \tag{24}$$

The total net gain is therefore

$$\alpha - (n + \beta \sum_{n+1}^{t} \rho_i) \,, \tag{25}$$

i.e.,

$$\alpha - \beta \sum_{1}^{t} \rho_i + V. \tag{26}$$

We define

$$m = \sum_{1}^{t} \rho_i , \tag{27}$$

and

$$x = \sum_{1}^{n} \rho_i . \tag{28}$$

Thus

$$V = \beta x - n \tag{29}$$

and the total net gain thus becomes

$$(\alpha - \beta m) + V \tag{30}$$

the same form as (14). Analogous to (18) let us take the quantity

$$f(n, x) = \frac{V}{V_{max}} \tag{31}$$

to be the measure of effectiveness.

The problem is now to compute V_{max}. At this point we must depart from the previous argument. The issue is: what value does perfect retrieval receive? Indeed, what is the characterization of perfect retrieval? The answer to this question is found by noting that a retrieval based on the notion of degree of relevance is a ranked retrieval; i.e., the collection of retrieved items is ranked, presumably according to estimates of the degree of relevance. Perfect retrieval is therefore defined as a listing of items according to magnitude of degree of relevance. Conceivably the degrees of relevance can become very small, in fact, so small that

$$\beta \rho_i \leqslant 1 .$$

This will be the case, of course, for items having no relevance to the information requirement whatsoever ($\rho_i = 0$); but of equal importance is the fact that, even in perfect retrieval, it will be more economical to ignore some retrieved items. Thus the value of perfect retrieval will be taken to be the maximum value as given by an optimal cutoff point. The expression for this value is obtained as follows: let $i_1, i_2, i_3, \ldots, i_\ell, \ldots$ be the sequence of accession numbers that gives perfect retrieval; i.e., the corresponding sequence of ρ_{i_ℓ} does not increase. Let λ be the largest ℓ such that

$$\beta \rho_{i_\ell} > 1 ,$$

Again, the cost to the user of processing a single item is taken to be one dollar. The value of perfect retrieval is then

$$V_{max} = \beta \sum_{\ell=1}^{\lambda} \rho_{i_\ell} - \lambda . \tag{32}$$

We then have the measure

$$f(n, x) = \frac{\beta x - n}{\beta \sum_{\ell=1}^{\lambda} \rho_{i_\ell} - \lambda} \tag{33}$$

In the particular case when all relevant items have the characteristic that $\beta\rho_i > 1$, (33) becomes

$$f(n, x) = \frac{\beta x - n}{\beta m - \lambda} \tag{34}$$

It is of interest to put this in the form (21). Again we define p as the reciprocal of V_{max} and use the abbreviations

$$R = \frac{x}{m} , \tag{35}$$

$$I = n - \lambda R , \tag{36}$$

so that (34) becomes

$$f(n, x) = R - pI \tag{37}$$

The quantity R is the proportion of relevant material retrieved and I is the effective amount of irrelevant material retrieved (in the unweighted case I is simply the number of irrelevant documents). The use of (37) as a measure of retrieval effectiveness has been reported elsewhere.*

7.5 EXTENSION TO SYSTEM EFFECTIVENESS

The measure described above appears to be a complete solution for the retrieval effectiveness of a system acting on a single query. It is obvious that this measure must depend on a parameter related to the value of the information desired (otherwise total retrieval would always be the best). The problem now is to extend this to an evaluation for an entire set of queries.

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*op. cit., footnote *, page 68.

For a particular query j in the set we will obtain the score

$$f_j = R_j - p_j I_j \tag{38}$$

where p_j is the value of $1/V_{max}$ for the particular problem. It is quite plausible to assume that in the entire set of queries the sets of numbers p_j, $j = 1, 2, \ldots,$ and I_j, $j = 1, 2, \ldots,$ are independent. The definition of independence that appears appropriate here is that the coefficient of linear correlation between the number sets is zero. This is equivalent to saying that the mean of the products $p_j I_j$ over the set of queries is equal to the product of the means. This will be the case, for instance, if the queries are sufficiently uniform in value so that p is constant; or that the file content and retrieval procedure is sufficiently stable to yield constant I. The reasonable and simplifying assumption of independence thus allows the computation of the mean-value score:

$$\overline{f} = \overline{R} - \overline{p}\,\overline{I} \tag{39}$$

where $\overline{R}$, $\overline{I}$, and $\overline{p}$ are the mean-values of R, I, and p, respectively. This equation involving $\overline{f}$ and $\overline{p}$ is therefore taken to characterize the retrieval effectiveness of the information system. The score $\overline{f}$ necessarily involves the parameter $\overline{p}$. Figure 6 shows the graphical characterization. The intercept on the $\overline{f}$ - axis is given by $\overline{R}$, the slope is given by the negative of $\overline{I}$.

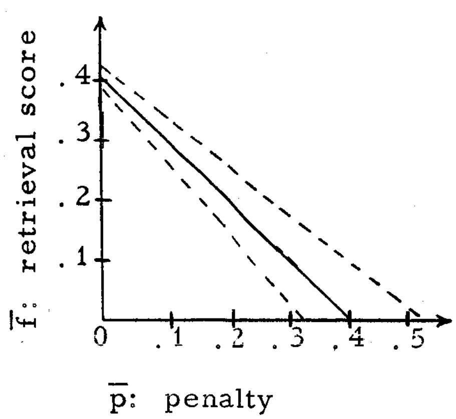

Figure 6. Characterization of a Retrieval System as a Linear Relation between Retrieval Score and Penalty Coefficient

In Figure 6, the solid line is the graph for the mean values $\overline{R}$, $\overline{I}$. The dotted lines give a graphical representation of reliability data. These are obtained by calculating the standard deviations of the means, $\sigma_{\overline{R}}$, $\sigma_{\overline{I}}$. The lower line is thus

$$\overline{f} = (\overline{R} - \sigma_{\overline{R}}) - \overline{p}\,(\overline{I} + \sigma_{\overline{I}}), \tag{40}$$

the upper line is

$$\overline{f} = (\overline{R} + \sigma_{\overline{R}}) - \overline{p}\,(\overline{I} - \sigma_{\overline{I}}), \tag{41}$$

To compare two systems, we then overlay the graphs of (39), (40), (41). If there is a clear domination of the graphs of one system over the graphs of the other, then the problem is solved. Suppose this is not the case; then a decision must be made based on an estimate of the magnitude of $\overline{p}$. How can this be done? Recall that $\overline{p}$ is the cost to the user of processing a single retrieved item relative to the maximum net gain possible from the search. The estimate will depend on the type of item retrieved. This question of estimation is open, but it appears that it is not unsolvable. Exact values are not necessary, but only gross estimates. For example, in a bibliographic search which produces abstracts the value of $\overline{p}$ can be taken as rather small. Another consideration is that estimates can be obtained by an intuitive evaluation of the equivalence of search outputs in particular situations. For example, suppose one method produces one-third of the relevant material, but no irrelevant. Suppose a second method produces all relevant material plus i irrelevant items. By letting i increase, we can speculate about the point at which the two methods are equally effective. Such considerations will allow estimates of the range of value of $\overline{p}$. Although subjective, it is plausible to assume that there will be some uniformity among different evaluators. Certainly, this can be tested. At any rate, these graphical representations appear to be a convenient tool for decisions on system design.

Finally, let us comment on the case of a ranked retrieval. That is to say, the file items are ranked (for the j^{th} query) by the magnitude of the selection number, s_{ij} (see Section 7.1). The first step in approaching this problem is the interpretation of what constitutes the output. Recall that we have been compelling the user to process all output items; i.e., he is not permitted to operate with his own selection procedure on the system output. If we now permit the user to process the output items successively, and choose at each step whether or not he will proceed, then we can define the output to consist of the processed items. The effectiveness can then be measured by the same graphical scheme as before. This seems reasonable as it certainly incorporates the ranking data. However, new complexity is introduced into the implementation of the method; namely, test participants are required to process the output.

A second approach is to correlate the two rankings given by perfect retrieval and by the selection procedure. We must "weight" the rankings however, for earlier misranking is more serious than later misranking. This is precisely because of the penalty coefficient. The decision to continue processing will be based on the information already obtained, and the gain to be obtained by continuing will be reduced accordingly. Thus p will be a non-decreasing step function, which increases after each relevant item is processed.

7.6 CONCLUSIONS AND RECOMMENDATIONS

The measures proposed above can be used for the following purposes: (1) to test an existing system; (2) to compare alternative systems or subsystems (e.g., (a) alternative search procedures, (b) depth of indexing, (c) request formulation devices); (3) as a tool for management decisions. As pointed out in Section 3, they can also be used to evaluate the successive stages in system improvement.

The steps in implementation are to select an appropriate sample of user information requirements (e.g., information retrieval queries, requests for bibliographies, statements of fields of interest, etc.);

a test "library" (perhaps built up gradually by selecting a certain proportion of acquisitions to go into this test library); judgments of perfect retrieval; the graphical characterizations as described in Section 7.5.

It is recommended that this tool be given consideration as part of a systematic procedure for system improvement and quality control.

BIBLIOGRAPHY

This list of articles, books, and reports is intended to serve as an entry point to the literature, in the subject categories chosen as having relevance to the problems discussed in the present Report. The selection of items was made jointly on the bases of excellence, and timeliness. The categories will be found in alphabetical sort, the papers within category, in reversed chronological order. Several useful bibliographies with a small overlap, both among themselves and with this Bibliography, are included as means of furthering the scope of this Bibliography into less centrally related fields. The bibliography sections of the papers herein mentioned form, in addition, a chain by which further references can be found. Thus, as with any bibliography, the scope extends far beyond what is here shown, or known to us.

ABSTRACTING

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APPENDIX A
FRAGMENT RETRIEVAL STUDY

A-1. RETRIEVAL QUESTIONS FOR TASK 3

1. What are the coefficients of viscosity for any mixtures of ammonia and hydrazine?

A. coefficients of viscosity
kinematic viscosity
η

B1. mixtures
combinations
compounds
blends
solutions

B2. ammonia
NH_3

B3. hydrazine
N_2H_4

2. What is the maximum flame temperature for the diborane liquid oxygen system?

A. maximum flame temperature
adiabatic flame temperature
combustion temperature

B1. diborane
D_2H_6

B2. liquid oxygen
LOX
LO_2
O_2

B3. system
combination
propellants
bipropellants

3. What are the compositions and melting points of condensation products in the allyl alcohol-hydrazine system?

A1. compositions
structural formulae
chemical formulae
structures

A2. melting points
m. p.
freezing points
f. p.
fusion temperature
melts at
freezes at
melts
freezes
solidifies at
solidifies

B1. condensation products
addition compounds

B2. allyl alcohol
C_3H_6O

B3. hydrazine
N_2H_4

B4. system
phase diagram

4. What are the column characteristics used for the determination of pentane impurity in HiCal 3?

A. column characteristics
chromatographic column
column
substrate
elluent
flowrate
temperature

B1. pentane
C_5H_{12}

B2. impurity
contamination
contaminant

B3. HiCal 3

5. What wave length is used for the determination of pentane impurity in HiCal 3 (a mixture of boron hydrons)?

A. wave length
wave number
microns
cm^{-1}

B1. pentane
C_5H_{12}

B2. impurity
contamination
contaminant

B3. HiCal 3

B4. boron
B

B5. hydrons

6. What quantity of additives will stabilize combustion of hydrocarbon fuels in small burners?

A. additives
catalyst
stabilizer

B1. stabilize
stable

B2. combustion
burning
flame
combust

B3. hydrocarbon fuels
jet fuels
RP
RJ
JP

B4. small burners
small engines
micro burners

7. What sample size is necessary for the determination of hydrazine and water mixtures in furfuryl alcohol-aniline?

A. sample size
amount
quantity

B1. determination
measurement

B2. hydrazine
N_2H_4

B3. water
H_2O

B4. furfuryl alcohol
$C_4H_3O \ CH_2OH$

B5. aniline
$C_6H_5NH_2$
C_6H_7N

8. What is the heat of formation of pentaborane-9?

A. heat of formation
enthalpy
ΔH_f
Q_j

B1. pentaborane-9
B_5H_9

9. In what yields has lithium fluoride been converted to lithium sulfate?

A. yields
efficiency
percentage
percent
amounts

B1. lithium fluoride
Li_2F_2
LiF

B2. converted
convert
conversion
converts
converting

B3. lithium sulfate
Li_2SO_4

10. What are the reaction products of sodium borohydride with organic amine salts?

A. reaction products
products
reaction

B1. sodium borohydride
$NaBH_4$

B2. organic
primary
secondary
tertiary
aliphatic

B3. amine salts

11. What catalyst can be used to prepare dipentaboryl methane?

A. catalyst
promoter
additive
in the presence of

B1. used
prepare
produce
make
product

B2. dipentaboryl methane

12. What kind of relationship exists between the number of red cells present when hemoglobin has been contaminated by decaborane?

A. red cells
erythrocytes

B1. hemoglobin

B2. contaminated
impurity
contaminant

B3. decaborane
$B_{10}H_{14}$

13. What are the minor contaminants in the solid exhaust products resulting from burning hydrazine fuels with potassium chlorate?

A. minor contaminants
minor products

B1. solid exhaust products
nongaseous products
condensed products

B2. burning
combustive
reactive
burns
reacts

B3. hydrazine fuels
hydrazine salts
N_2H_4

B4. potassium chlorate
$KC\ell O_3$

14. What are the principal (chemical) reactions between a single base solid propellant and a stabilizer on aging?

A. chemical reactions
reactions
chemistry
effects

B1. single base propellant
solid propellant

B2. stabilizer
stabilizes
stabilize
stable

B3. aging
age
aged

15. What is the structure of di-isopropoxyborane?

A. structure
molecular configuration

B1. di-isopropoxyborane

16. What is the atomic weight of boron?

A. atomic weight
at. wt.

B1. boron
B

17. Where can I obtain spectroscopically pure $B(CD_3)_3$? or
Where can I obtain the pure deuterium derivative of trimethyl borane?

A. spectroscopically pure
pure
uncontaminated
neat

B. $B(CD_3)_3$
deuterium derivative
trimethyl borane

18. What are the reaction products of hydrazine and salicylaldehyde?

A. reaction products
condensation products

B1. hydrazine
N_2H_4

B2. salicylaldehyde
$C_7H_6O_2$

19. Is diborane soluble in butane or pentane to the extent of at least 5 mole per cent?

A. diborane
B_2H_6

B1. soluble
miscible
dissolves
dissolved

B2. butane
C_4H_{10}

B3. pentane
C_5H_{12}

B4. 5 mole
five mole

B5. per cent
percent

20. How can diborane be synthesized?

A. diborane
B_2H_6

B1. synthesized
prepared
made
produced
make

21. What is the theoretical performance of the propellant combination inhibited red-fuming nitric acid in tetramethyltetrazine?

A. theoretical performance
characteristic velocity
c^*
specific impulse
is. p.
thrust coefficient
C_f

B1. propellant
bipropellant

B2. inhibited red-furming nitric acid
IRFNA

B3. tetramethyl tetrazine
$C_4H_{12}N_4$
TMT

22. Polyethylene is combustible with what mixtures of oxygen and nitrogen at ambient pressure?

A. polyethylene
$(CH_2)_n$
polyethene

B1. combustible
flammable
combusts
flame
combustion

B2. Oxygen
O_2

B3. nitrogen
N_2

B4. ambient pressure
atmospheric pressure

23. What are the methods for determining boron in non-acqueous solvents?

A. methods
procedures
methodology

B1. determining
finding

B2. boron
B

B3. non-acqueous
alcohol
amine
hydrazine

B4. solvents
liquid
solution
dissolves

24. Will nitrogen react with elemental boron?

A. nitrogen
N_2

B1. react
combine
attack
affect

B2. elemental
free
uncombined

B3. boron
B

25. What is the mechanism of pentaborane decomposition at high temperature?

A. mechanism

B1. pentaborane
B_5H_9

B2. decomposition
degeneration
deterioration
breakdown

B3. high temperature
300-400°F
high heat

26. What is the nuclear rocket propellant which has the highest specific impulse at 1000°K?

A. (nuclear) rocket

B1. propellant
working fluid

B2. highest

B3. specific impulse
characteristic velocity
is. p.

B4. at 1000°K
1000°Kelvin
1800°R
1800°Rankin

27. What is the flame temperature for gaseous oxygen in normal heptane at 100 atmospheres?

A. flame
combustion
burn

B1. temperature
heat
cold

B2. gaseous oxygen
GOX

B3. normal heptane
C_7H_{16}

B4. 100 atmospheres
1470 p. s. i.

28. What fuel is most effective for use with fluorine in upper-stage vehicle applications?

A. fuel
propellant

B1. effective
efficient
best

B2. fluorine
F_2

B3. upper-stage
second-stage
third-stage
fourth-stage

B4. vehicle
propulsion system

B5. applications
uses

29. What are the combustion limits of the hydrazines in air?

A. combustion
flammability
burning
flame

B1. limits

B2. hydrazine
N_2H_4
monomethylhydrazine
MMH
CH_6N_2
(unsymmetrical) dimethylhydrazine
UDMH
$C_2H_8N_2$

30. What are the combustion limits of hydrazine in air at 100°C? or
Are the hydrazines spontaneously inflammable in air at 100°C?

[Question 30 discarded]

31. How much does air collection increase the specific impulse of rocket systems?

A. air

B1. collection

B2. specific impulse
is.p.

B3. rocket
propulsion

B4. systems

32. All information on combustion of boron hydrides.

A. combustion
burning
reaction

B1. boron hydrides
B_5H_6
B_2H_6
$B_{10}H_{14}$
HiCal
HEF

33. What is the decomposition temperature of fluorine oxide?

A. decomposition
decomposed at
decomposes at

B1. temperature
heat

B2. fluorine oxide
O_3F_2
ozone difluoride

34. What factors influence the high frequency oscillations in rocket motors burning hydrocarbon (gases) in air?

A. influence
modify
change
cause
affect

B1. high frequency oscillations
high frequency fluctuation
high frequency instability

B2. rocket motors

B3. hydrocarbon gases
$(CH_2)_n$
jet
RP
RJ
JP

B4. air

35. List the heats of formation of chemical compounds.

A. heats of formation
H_f
Q_f

B1. chemical compounds
compounds

36. What is the compatibility with metals of fluorine compounds?

A. compatibility
reactivity
reaction
reacted
reacts

B1. metals
metallic

B2. F_2
OF_2
Oxygen difluoride
bifluorine oxide
O_3F_2
N_2F_4
tetrafluorohydrazine
NF_3
trifluoramine
HNF_2
difluoramine
NF_3O
trifluoramine oxide
HF
hydrogen fluoride

37. What are the known beryllium propellants used in the USSR?

A. beryllium
Be

B1. propellants
grain

B2. USSR
Russia
Soviet
Russian

38. Is dinitrotoluene used in solid propellants?

A. dinitrotoluene
$C_7H_6O_4N_2$
$C_7H_6N_2O_4$
DNT

B1. solid

39. What methods can be used to encapsulate hydrazine and ethylene?

A. encapsulate
coat

B1. hydrazine
N_2H_4

B2. ethylene
C_2H_4

40. What catalyst can be used to decompose hydrazine spontaneously?

A. catalyst
promoter
in the presence of

B1. decompose
ignite
spontaneously

B2. hydrazine
N_2H_4

41. What oxidizers can be used in rocket applications with boron?

A. oxidizers
nitrogen
ammonia
hydrazine

B1. rocket applications
high energy fuels
HEF
specific impulse
is. p.

B2. boron
B

A-2. SAMPLE OF CONCORDANCE

CONCORDANCE LISTING FOR CORPORA 6 060363 PAGE 132

PENTABORANE/9	1	24		1																		
PENTABORANES	3	24	4	2	24	7		24	10	1												
PENTABORYL	1	12	5	6																		
PENTAFLUORIDE	1	55	14	1																		
PENTANE		3		1	3	2	1	3	2	1	3	4	1	3	4	1	3	4	3	3	4	3
		3	5	1	3	5	1	3	7	3	3	8	9	3	8	12	3	9	1	3	9	1
		3	14	1	3	16	1	3	16	2	3	16	3	3	16	4	3	17	2	3	19	4
		23		1	23	2	1	23	3	1	23	5	1	23	7	1	23	7	3	23	11	2
	31	23	12	7	23	14	2	23	14	1												
PENTOXY-1	1	16	26	3																		
PER		3	7	3	3	8	5	3	19	3	5	18	5	6	2	3	6	3	1	6	4	4
		6	4	4	6	4	5	6	11	2	6	16	1	6	22	3	6	28	1	6	29	2
		6	30	1	6	34	1	6	36	1	7	19	3	10	2	2	10	2	3	10	19	1
		10	19	1	10	19	2	10	20	1	10	20	1	10	20	1	10	20	2	10	21	1
		10	21	4	10	27	2	10	28	1	10	28	2	10	30	2	10	30	4	10	36	3
		10	43	3	10	43	4	10	43	5	10	45	3	10	46	2	10	46	2	10	47	1
		10	48	4	10	52	1	23	3	1	24	21	3	45	11	2	45	11	2	47	10	4
	51	52	11	3	56	22	1															
PERCENT		3	4	1	3	4	3	3	7	2	3	8	9	3	9	1	3	9	2	3	9	2
		3	9	3	3	15	4	5	5	9	5	10	2	5	10	8	5	10	10	5	20	4
		5	21	4	5	21	5	5	21	8	5	22	5	5	22	11	7	11	5	7	12	3
		7	22	5	7	23	3	11	2	1	11	13	1	11	16	1	11	16	2	11	19	1
		11	25	2	11	25	4	11	27	1	12	2	1	12	2	3	12	9	9	12	9	9
		12	9	9	12	9	10	12	9	10	12	9	10	12	9	12	12	22	1	12	23	2
		14	7	2	14	7	2	14	11	3	14	11	3	14	16	1	14	16	1	16	29	2
		18	9	2	18	9	2	18	9	3	18	9	3	18	15	2	18	15	2	18	15	5
		18	24	1	19	3	2	19	3	3	19	3	3	19	17	8	19	32	2	19	36	1
		19	36	2	19	36	2	19	37	2	23	11	2	42	7	8	42	9	7	42	15	1
		42	15	4	42	15	5	42	15	5	42	16	4	42	16	4	42	16	5	42	16	5
		42	16	5	42	16	6	42	22	3	42	27	2	47	10	2	47	11	5	52	15	1
	88	52	19	4	52	19	4	55	18	1	55	21	4									
PERCENTAGE	3	14	5	1	42	23	4	42	27	4												
PERCENTAGES	1	19	3	3																		
PERCENT.	2	11	27	3	55	23	1															
PERCHLORATE	1	52	10	2																		

A-3. SAMPLE RETRIEVAL SHEET

Question Number	Documents Retrieved	Abstracts Retrieved	Paragraphs Retrieved	Abstract and Document Sentences Retrieved (underlined sentences are also sentences of the abstract)	Notes
32	69	69	69-3, 69-7 69-8, 69-9 69-21	69-8-1, 69-7-1, 69-7-3 69-9-3, 69-21-5, 69-21-6 69-3-2, 69-8-2, 69-2-1 69-3-1, 69-4-1, 69-31-1 69-9-1, 69-10-1, 69-10-2 69-11-1, 69-11-2, 69-11-4 69-19-4, 69-22-2, 69-23-4 69-29-2	
32	81	81	8-2	81-11-1, 81-20-3, 81-25-2 81-26-1, 81-2-2, 81-24-4 81-26-2, 81-2-1, 81-2-3 81-6-2, 81-9-1, 81-10-2 81-15-1, 81-28-3	
33	44	none	44-15, 44-16	44-16-1, 44-15-1	good retrieval: terse and adequate
34	45	45	45-2, 45-3	45-0-1, 45-7-2, 45-32-1, 45-32-3 45-20-2, 45-26-2, 45-23-3, 45-32-6 45-18-1, 45-21-1, 45-3-1, 45-6-2 45-7-1, 45-16-3, 45-23-1, 45-6-1 45-7-3, 45-26-3, 45-32-5, 45-2-2 45-25-2	paragraph 3 is the best possible answer (2+3 is also good)
35	49	49	49-4, 49-5 49-8	49-4-5, 49-5-1, 49-6-2, 49-8-1, 49-19-1, 49-20-1, 49-26-1, 49-27-1 49-31-1, 49-4-1, 49-7-1	
36	10	none	none	10-12-1, 10-12-3	question at once too general and not expanded enough ('metals') bad question

A-4. INSTRUCTIONS FOR RETRIEVAL EVALUATION

Each manila folder contains one question and one retrieval set for each document judged responsive to the question. A retrieval set consists of an answer document and one to four sets of fragments derived from the answer document. Fragment sets are arranged in levels according to size, going from the smallest to the largest. Levels are indicated by the red numbers in the upper right hand corner.

Directions for evaluation of retrieval sets are as follows:

A. If the folder contains fragment sets from only one document:

1. Read fragment marked with a red 1 in the upper right hand corner.

2. Indicate a judgment of relevance ("irrelevant", "partial answer", etc.) by marking the appropriate box in the row numbered 1 on the retrieval scoring form.

3. Proceed with levels 2, 3, and 4 in the same manner.

4. For the complete document (level 5), the following additional information should be furnished:

   a. Underline all sentences which are relevant to the question.

   b. Underline a second time only those sentences which, taken together, constitute a minimal complete answer.

B. If the folder contains fragment sets from more than one document:

1. Rate the individual fragments on level 1 as described above under A.

2. Taking all level 1 fragments together, assign a single rating to the group of fragments (use the scoring form marked "all").

3. Proceed with levels 2, 3, and 4 in the same manner.

4. On level 5, provide information outlined under A. 4 above for each document.

C. Consider graphs or tables referred to as having been retrieved.

Question No. 34
Document No. 45

A-5. RETRIEVAL SCORING FORM

Fragment Level \ Response	Irrelevant	Partial Answer	Answer Can Be Inferred	Complete Answer
1		√		
2				√
3	√			
4	√			
5 (Document)				√

A-6. SAMPLE QUESTION AND ANSWER SET

34. What factors influence the [high frequency oscillations / fluctuation / instability] in rocket motors burning [hydrocarbon gases / (CH_2) / jet / RP / RJ / JP] in air? (Docs. 45, 6)

A-6.1 Level 1

Question No. 34 Document No. 45-C

2. The experiments reported herein were concerned with the determination of some of the factors which contribute to the occurrence of transverse and longitudinal modes of combustion oscillation in rocket motors burning gases. Three rocket motors having different combustion chamber geometries were employed, using gaseous hydrocarbon fuels premixed with air as propellants; the fuels were methane, ethane, superheated propane, ethylene, and hydrogen.

3. The findings indicated that the incidence and amplitude of the combustion pressure oscillations were profoundly influenced by the coupled effects of (a) the chemical composition of the fuels, and (b) the aspect ratio of the cylindrical combustion chamber.

A-6.2 Level 2

Question No. 34 Document No. 45-A

2-2 Three rocket motors having different combustion chamber geometries were employed, using gaseous hydrocarbon fuels premixed with air as propellants; the fuels were methane, ethane, superheated propane, ethylene, and hydrogen.

3-1 The findings indicated that the incidence and amplitude of the combustion pressure oscillations were profoundly influenced by the coupled effects of (a) the chemical composition of the fuels, and (b) the aspect ratio of the cylindrical combustion chamber.

6-1 A series of experiments was recently conducted to determine the influence of the chemical composition of different gaseous hydrocarbon fuels (burned with air) upon high frequency combustion oscillations in a rocket motor.

7-1 Because the rocket motors employed in the experiments had combustion chambers of different diameters and lengths for determining the effects of combustion chamber geometry, the effects due to the chemical reactivities of the fuels cannot be completely segregated from those due to afore-mentioned differences in geometry.

7-2 In this paper, however, the major emphasis will be placed upon the effect of the fuel composition.

16-3 In general, the relative effects due to chemistry noted in the experiments with the 7 in. diameter motors were the same as those obtained with the 14 in. diameter motors.

21-1 Another interesting result of the effect of chemical composition is that certain transverse modes were characteristic for a given propellant combination within the range of chamber pressures investigated.

23-1 A discussion of the effects due to chemical differences in the fuels is facilitated by considering a mechanism presented in References (4) and (5) which was postulated to explain the initiation and propagation of a longitudinal mode; it is believed that the mechanism explains the transverse modes also.

32-1 Consideration of the relative reactivities and heat release rates of the fuels used in these experiments explain the following combustion oscillation phenomena for a premixed gaseous propellant system: Saturated hydrocarbons exhibit less tendency to cause oscillations than the unsaturated hydrocarbons and hydrogen.

32-3 When the lower critical length of the longitudinal mode is exceeded, it is highly probable that there will be an interaction between the longitudinal and transverse modes, which may cause a shift in the instability region, and amplitudes of oscillation which are higher than normal.

32-6 Increasing the fuel reactivity causes a. a broadening of the range of equivalence ratios for the instability region; b. a lowering of the chamber pressure at which the instability region originates; c. an augmenting of the amplitude of the pressure oscillations within the instability region.

A-6.3 Level 3

Question No. 34 | Document No. 45-B

0-1 ON THE EFFECT OF FUEL COMPOSITION ON HIGH FREQUENCY OSCILLATIONS IN ROCKET MOTORS BURNING PREMIXED HYDROCARBON GASES AND AIR

2-2 Three rocket motors having different combustion chamber geometries were employed, using gaseous hydrocarbon fuels premixed with air as propellants; the fuels were methane, ethane, superheated propane, ethylene, and hydrogen.

3-1 The findings indicated that the incidence and amplitude of the combustion pressure oscillations were profoundly influenced by the coupled effects of (a) the chemical composition of the fuels, and (b) the aspect ratio of the cylindrical combustion chamber.

6-1 A series of experiments was recently conducted to determine the influence of the chemical composition of different gaseous hydrocarbon fuels (burned with air) upon high frequency combustion oscillations in a rocket motor.

6-2 In all cases the fuel and air were premixed before being injected into the combustion chamber, thereby eliminating the effects of such variables as atomization, vaporization, mixing, etc., which enter into the combustion of liquid propellants.

7-1 Because the rocket motors employed in the experiments had combustion chambers of different diameters and lengths for determining the effects of combustion chamber geometry, the effects due to the chemical reactivities of the fuels cannot be completely segregated from those due to afore-mentioned differences in geometry.

7-2 In this paper, however, the major emphasis will be placed upon the effect of the fuel composition.

7-3 The influence of differences in combustion chamber geometry is presented in Reference (1).[3]

16-3 In general, the relative effects due to chemistry noted in the experiments with the 7 in. diameter motors were the same as those obtained with the 14 in. diameter motors.

18-1 Figure 3 presents the peak-to-peak pressure amplitude as a function of the combustion chamber length, and illustrates the effect of chamber length upon the maximum amplitudes of the pressure oscillations.

20-2 It was observed that for methane-air, increasing the chamber length caused the toes of the instability regions for the transverse modes to be displaced to higher chamber pressures in all cases.

21-1 Another interesting result of the effect of chemical composition is that certain transverse modes were characteristic for a given propellant combination within the range of chamber pressures investigated.

23-1 A discussion of the effects due to chemical differences in the fuels is facilitated by considering a mechanism presented in References (4) and (5) which was postulated to explain the initiation and propagation of a longitudinal mode; it is believed that the mechanism explains the transverse modes also.

23-3 The increased temperature and pressure of the gases causes an accelerated chemical reaction rate (or heat release rate) behind the pressure front which drives and sustains the pressure wave.

25-2 The boundaries of an instability region and the amplitudes of some of the oscillations within the region may be explained by referring to Fig. 5, which is a qualitative presentation of the heat release rate versus the equivalence ratio for several hydrocarbon air propellant combinations at a given chamber pressure.

26-2 It appears reasonable that the same type of interaction caused the amplitude shift observed in Fig. 3.

26-3 The methane-air propellants did not exhibit such shifts thus demonstrating another influence of the chemistry of the propellant combination.

32-1 Consideration of the relative reactivities and heat release rates of the fuels used in these experiments explain the following combustion oscillation phenomena for a premixed gaseous propellant system: Saturated hydrocarbons exhibit less tendency to cause oscillations than the unsaturated hydrocarbons and hydrogen.

32-3 When the lower critical length of the longitudinal mode is exceeded, it is highly probable that there will be an interaction between the longitudinal and transverse modes, which may cause a shift in the instability region, and amplitudes of oscillation which are higher than normal.

32-5 The characteristics of the instability region are influenced by fuel reactivity.

Question No. 34 Document No. 45-B

32-6 Increasing the fuel reactivity causes

a. a broadening of the range of equivalence ratios for the instability region;

b. a lowering of the chamber pressure at which the instability region originates;

c. an augmenting of the amplitude of the pressure oscillations within the instability region.

A-6.4 Level 4

PAR	SENT	DOCUMENT NUMBER 45 PAGE 1

ABSTRACT BASED ON CUE TITLE LOC. WTS.

ON THE EFFECT OF FUEL COMPOSITION ON HIGH FREQUENCY OSCILLATIONS IN ROCKET MOTORS BURNING PREMIXED HYDROCARBON GASES AND AIR (AD255031)

J. R. OSBORN AND J. M. BONNELL

PAR	SENT	TEXT
1	0	ABSTRACT
2	1	THE EXPERIMENTS REPORTED HEREIN WERE CONCERNED WITH THE DETERMINATION OF SOME OF THE FACTORS WHICH CONTRIBUTE TO THE OCCURRENCE OF TRANSVERSE AND LONGITUDINAL MODES OF COMBUSTION OSCILLATION IN ROCKET MOTORS BURNING GASES.
2	2	THREE ROCKET MOTORS HAVING DIFFERENT COMBUSTION CHAMBER GEOMETRIES WERE EMPLOYED, USING GASEOUS HYDROCARBON FUELS PREMIXED WITH AIR AS PROPELLANTS., THE FUELS WERE METHANE, ETHANE, SUPERHEATED PROPANE, ETHYLENE, AND HYDROGEN.
3	1	THE FINDINGS INDICATED THAT THE INCIDENCE AND AMPLITUDE OF THE COMBUSTION PRESSURE OSCILLATIONS WERE PROFOUNDLY INFLUENCED BY THE COUPLED EFFECTS OF (A) THE CHEMICAL COMPOSITION OF THE FUELS, AND (B) THE ASPECT RATIO OF THE CYLINDRICAL COMBUSTION CHAMBER.
4	1	THE RESULTS INDICATED THAT THE FOLLOWING MEASURES OF THE BEHAVIOR OF COMBUSTION OSCILLATIONS WERE FUNCTIONS OF THE CHEMICAL REACTIVITY OF THE FUEL.
4	4	(C) THE COMBUSTION CHAMBER LENGTH BELOW WHICH LONGITUDINAL OSCILLATIONS WILL NOT OCCUR (THE LOWER CRITICAL LENGTH).
5	0	INTRODUCTION
6	1	A SERIES OF EXPERIMENTS WAS RECENTLY CONDUCTED TO DETERMINE THE INFLUENCE OF THE CHEMICAL COMPOSITION OF DIFFERENT GASEOUS HYDROCARBON FUELS (BURNED WITH AIR) UPON HIGH FREQUENCY COMBUSTION OSCILLATIONS IN A ROCKET MOTOR.
7	1	BECAUSE THE ROCKET MOTORS EMPLOYED IN THE EXPERIMENTS HAD COMBUSTION CHAMBERS OF DIFFERENT DIAMETERS AND LENGTHS FOR DETERMINING THE EFFECTS OF COMBUSTION CHAMBER GEOMETRY, THE EFFECTS DUE TO THE CHEMICAL REACTIVITIES OF THE FUELS CANNOT BE COMPLETELY SEGREGATED FROM THOSE DUE TO AFORE-MENTIONED DIFFERENCES IN GEOMETRY.
7	2	IN THIS PAPER, HOWEVER, THE MAJOR EMPHASIS WILL BE PLACED UPON THE EFFECT OF THE FUEL COMPOSITION.

PAR	SENT	
8	0	EXPERIMENTAL APPARATUS
12	0	EXPERIMENTAL RESULTS
13	0	LONGITUDINAL MODE RESULTS
14	1	REFERENCES (4) AND (5) PRESENT THE RESULTS OF THE STUDIES OF THE LONGITUDINAL MODE OF COMBUSTION PRESSURE OSCILLATION FOR THE FOLLOWING PROPELLANT COMBINATIONS.. SUPERHEATED PROPANE AND AIR, ETHANE AND AIR, METHANE AND AIR, AND ETHYLENE AND AIR.
15	0	TRANSVERSE MODE RESULTS
16	3	IN GENERAL, THE RELATIVE EFFECTS DUE TO CHEMISTRY NOTED IN THE EXPERIMENTS WITH THE 7 IN. DIAMETER MOTORS WERE THE SAME AS THOSE OBTAINED WITH THE 14 IN. DIAMETER MOTORS.
16	4	CONSEQUENTLY, THE DISCUSSION WILL BE RESTRICTED TO RESULTS OBTAINED WITH THE 7 IN. DIAMETER MOTORS.
21	1	ANOTHER INTERESTING RESULT OF THE EFFECT OF CHEMICAL COMPOSITION IS THAT CERTAIN TRANSVERSE MODES WERE CHARACTERISTIC FOR A GIVEN PROPELLANT COMBINATION WITHIN THE RANGE OF CHAMBER PRESSURES INVESTIGATED.
22	0	DISCUSSION OF RESULTS
23	1	A DISCUSSION OF THE EFFECTS DUE TO CHEMICAL DIFFERENCES IN THE FUELS IS FACILITATED BY CONSIDERING A MECHANISM PRESENTED IN REFERENCES (4) AND (5) WHICH WAS POSTULATED TO EXPLAIN THE INITIATION AND PROPAGATION OF A LONGITUDINAL MODE.. IT IS BELIEVED THAT THE MECHANISM EXPLAINS THE TRANSVERSE MODES ALSO.
24	4	SINCE THE MOST REACTIVE FUELS REQUIRE LESS PREPARATION TIME THAN RELATIVELY UNREACTIVE FUELS, THE PERIOD OF OSCILLATION MAY BE LESS, AND THE CRITICAL LENGTH OF THE CHAMBER MAY BE SHORTER.
30	1	IT IS ALSO INTERESTING TO NOTE THAT THE RESULTS INDICATE THAT THE NUMBER OF DIFFERENT TRANSVERSE MODES WHICH A PROPELLANT COMBINATION IS CAPABLE OF SUSTAINING APPEARS TO BE A FUNCTION OF THE REACTIVITY OF THE FUEL AS WELL AS A FUNCTION OF THE COMBUSTION CHAMBER GEOMETRY.
30	2	IN THE CHAMBER PRESSURE RANGE INVESTIGATED, THE SATURATED HYDROCARBONS SUSTAINED ONLY THE FUNDAMENTAL TRANSVERSE MODES WHILE THE UNSATURATED HYDROCARBONS AND ALSO HYDROGEN WERE CAPABLE OF SUSTAINING COMBINATIONS OF MODES, AND MODES HIGHER THAN FIRST ORDER.

PAR	SENT	
31	0	CCNCLUSIONS
32	1	CCNSIDERATION OF THE RELATIVE REACTIVITIES AND HEAT RELEASE RATES OF THE FUELS USED IN THESE EXPERIMENTS EXPLAIN THE FOLLOWING COMBUSTION OSCILLATION PHENOMENA FOR A PREMIXED GASEOUS PROPELLANT SYSTEM.. 1. SATURATED HYDROCARBONS EXHIBIT LESS TENDENCY TO CAUSE OSCILLATIONS THAN THE UNSATURATED HYDROCARBCNS AND HYDROGEN.
32	2	2. THE MAGNITUDE OF THE LOWER CRITICAL LENGTH FOR THE LONGITUDINAL MODE OF OSCILLATION IS SMALLER FOR THE MORE REACTIVE FUELS.
32	3	3. WHEN THE LOWER CRITICAL LENGTH OF THE LONGITUDINAL MODE IS EXCEEDED, IT IS HIGHLY PROBABLE THAT THERE WILL BE AN INTERACTION BETWEEN THE LONGITUDINAL AND TRANSVERSE MODES, WHICH MAY CAUSE A SHIFT IN THE INSTABILITY REGION, AND AMPLITUDES OF OSCILLATION WHICH ARE HIGHER THAN NORMAL.
32	4	FOR THE HIGHLY REACTIVE FUELS THIS OCCURRED AT SHORTER CHAMBER LENGTHS THAN FOR LESS REACTIVE FUELS.
32	6	INCREASING THE FUEL REACTIVITY CAUSES.. A. A BROADENING OF THE RANGE OF EQUIVALENCE RATIOS FOR THE INSTABILITY REGION., B. A LOWERING OF THE CHAMBER PRESSURE AT WHICH THE INSTABILITY REGION ORIGINATES., C. AN AUGMENTING OF THE AMPLTUDE OF THE PRESSURE OSCILLATIONS WITHIN THE INSTABILITY REGION.
32	7	5. WHEREAS RELATIVELY UNREACTIVE SATURATED HYDROCARBON FUELS MAY SUPPORT A SINGLE FUNDAMENTAL TRANSVERSE MODE, MORE REACTIVE FUELS ARE CAPABLE OF SUSTAINING MORE THAN ONE FUNDAMENTAL MODE SIMULTANEOUSLY AS WELL AS SECOND ORDER MODES.

0045 ON THE EFFECT OF FUEL COMPOSITION ON HIGH FREQUENCY OSCILLATIONS IN ROCKET MOTORS BURNING PREMIXED HYDROCARBON GASES AND AIR AD 255031/D

J. R. Osborn[1] and J. M. Bonnell[2]

~~Purdue University~~

ABSTRACT

The experiments reported herein were concerned with the determination of some of the factors which contribute to the occurrence of transverse and longitudinal modes of combustion oscillation in rocket motors burning gases. Three rocket motors having different combustion chamber geometries were employed, using gaseous hydrocarbon fuels premixed with air as propellants; the fuels were methane, ethane, superheated propane, ethylene, and hydrogen.

The findings indicated that the incidence and amplitude of the combustion pressure oscillations were profoundly influenced by the coupled effects of (a) the chemical composition of the fuels, and (b) the aspect ratio of the cylindrical combustion chamber.

The results indicated that the following measures of the behavior of combustion oscillations were functions of the chemical reactivity of the fuel.

(a) The relative ability of the different gaseous propellant combinations to support combustion oscillations.

(b) The shape and origin of the instability region of the transverse modes, and the amplitudes of the oscillations within the region.

(c) The combustion chamber length below which longitudinal oscillations will not occur (the lower critical length).

(d) The tendency for interactions between transverse and longitudinal modes to occur.

(e) The types of modes of oscillation.

1. Associate Professor of Mechanical Engineering.
2. Research Assistant.

INTRODUCTION

A series of experiments was recently conducted to determine the influence of the chemical composition of different gaseous hydrocarbon fuels (burned with air) upon high frequency combustion oscillations in a rocket motor. In all cases the fuel and air were premixed before being injected into the combustion chamber, thereby eliminating the effects of such variables as atomization, vaporization, mixing, etc., which enter into the combustion of liquid propellants.

Because the rocket motors employed in the experiments had combustion chambers of different diameters and lengths for determining the effects of combustion chamber geometry, the effects due to the chemical reactivities of the fuels cannot be completely segregated from those due to afore-mentioned differences in geometry. In this paper, however, the major emphasis will be placed upon the effect of the fuel composition. The influence of differences in combustion chamber geometry is presented in Reference (1).[3]

EXPERIMENTAL APPARATUS

The rocket motor utilized in studies of the longitudinal mode of combustion oscillation had a combustion chamber diameter of 3 3/8 in. The two motors utilized in the transverse mode investigations had combustion chambers of 7 in. and 14 in. inside diameter. In all cases the lengths of the combustion chambers were altered by adding spacers.

The pressure oscillations were sensed by Photocon pressure transducers mounted in the wall of the combustion chamber. A complete description of the instrumentation, rocket motors, and all other test apparatus is found in References (2), (3), (4), and (5).

3 ~~Numbers in parentheses indicate references at the end of the paper.~~

METHANE,

Air was used as the oxidizer with the following gaseous fuels; ethane, superheated propane, ethylene, and hydrogen. All of the fuels were technical grade of 95 per cent purity except hydrogen which was 99.5 per cent pure.

EXPERIMENTAL RESULTS

Longitudinal Mode Results

References (4) and (5) present the results of the studies of the longitudinal mode of combustion pressure oscillation for the following propellant combinations: superheated propane and air, ethane and air, methane and air, and ethylene and air. These experiments determined the lower critical lengths[4] for the longitudinal mode for the afore-mentioned propellant combinations. Figure 1 presents the amplitude of longitudinal pressure oscillations as a function of the chamber length for ethylene-air, ethane-air, and methane-air propellants, for a steady state combustion pressure of 40 psia and constant equivalence ratios. The combustion chamber lengths at which the amplitudes of the oscillations approach zero are the lower critical lengths.

Transverse Mode Results

The experiments concerned with the transverse mode of oscillation were conducted with methane, ethylene, and hydrogen as the fuels. The fuels were selected for their different degrees of saturation and chemical reactivity (see Appendix A). In general, the relative effects due to chemistry noted in the experiments with the 7 in. diameter motors were the same as those obtained with the 14 in. diameter motors. Consequently, the discussion will be restricted to results obtained with the 7 in. diameter motors.

Figure 2 presents the instability boundary curves[5] for hydrogen, ethylene, and methane. The boundary curves are plots of equivalence ratio as a function of chamber pressure, and were obtained with the 7 in. diameter motor, 2 in. length. The instability regions for methane and ethylene fuels are presented in References (1), (2), and (3).

Figure 3 presents the peak-to-peak pressure amplitude as a function of the combustion chamber length, and illustrates the effect of chamber length upon the maximum amplitudes[6] of the pressure oscillations. The experiments were conducted at a steady state combustion pressure of 160 psia burning methane-air and ethylene-air as the propellants. It is seen that in the case of ethylene-air there is a shift in trend of the oscillation amplitude at the 6 in. length; for the methane-air propellants no comparable shift was found. The same type of amplitude shift for ethylene-air was also observed with the 14 in. diameter motor. Experiments conducted with other steady state chamber pressures gave the same trends for the oscillation amplitudes but, of course, different magnitudes for the maximum amplitudes.

Figure 4 presents the maximum amplitude of the pressure oscillations as a function of steady state chamber pressure for the hydrogen-air, ethylene-air, and methane-air propellant combinations.

In References (1), (2), and (3) the instability regions for different chamber lengths of the 7 in. and the 14 in. diameter motors were presented for the methane-air and ethylene-air propellants. It was observed that for methane-air, increasing the chamber length caused the toes of the instability regions for the transverse modes to be displaced to higher chamber pressures in all cases. For ethylene-air, however, in both the 7 in. and 14 in. diameter motors, the toes of the instability regions moved to higher chamber pressures until a length/diameter ratio of approximately 1.0 was reached. At that length the toe of the instability region occurred at a lower chamber pressure and then the toes of the regions again progressed toward higher chamber pressures as chamber length increased.

Another interesting result of the effect of chemical composition is that certain transverse modes were characteristic for a given propellant combination within the range of chamber pressures investigated. For the methane-air propellant combination, the mode of oscillation was almost exclusively the first tangential.[7] For ethylene-air propellants the modes were chiefly the first tangential, the first

4. The lower critical length is the combustion chamber length below which longitudinal oscillations will not occur.
5. The boundary curve for an instability region denotes unstable combustion to the right of the boundary and either stable combustion or no combustion to the left of the boundary curve.
6. The maximum amplitude refers to the maximum amplitude at a given chamber pressure without restriction on equivalence ratio.
7. The classification of "tangential" type modes used herein includes both "standing" and "traveling" waves.

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tangential with a superimposed radial, and an occasional trace of a second tangential. For hydrogen-air propellants, the first and second tangential modes were common, with traces of a superimposed radial mode.

DISCUSSION OF RESULTS

A discussion of the effects due to chemical differences in the fuels is facilitated by considering a mechanism presented in References (4) and (5) which was postulated to explain the initiation and propagation of a longitudinal mode; it is believed that the mechanism explains the transverse modes also. In substance, the mechanism states that in a combustion chamber a pressure wave is initiated by some pressure disturbance, and the subsequent passage of the pressure wave through burning and unburned propellants adiabatically compresses these hot gases. The increased temperature and pressure of the gases causes an accelerated chemical reaction rate (or heat release rate) behind the pressure front which drives and sustains the pressure wave. Reference (6) supports this mechanism with experimental evidence.

As has been stated, this mechanism was employed (4) for explaining the existence of the lower critical length and to postulate the probable existence (5) of the upper critical length. The experiments of References (7) and (8) with liquid propellants demonstrate the existence of a lower and an upper critical length. Consideration of the chemistry of the propellants can explain the relative position of the curves of Fig. 1. Since the most reactive fuels require less preparation time than relatively unreactive fuels, the period of oscillation may be less, and the critical length of the chamber may be shorter. Moreover, for a given length, the more reactive fuel will produce higher amplitude oscillations for the above reasons.

Consideration of chemical reactivity can also aid in the discussion of the instability regions. The boundaries of an instability region and the amplitudes of some of the oscillations within the region may be explained by referring to Fig. 5, which is a qualitative presentation of the heat release rate versus the equivalence ratio for several hydrocarbon air propellant combinations at a given chamber pressure. If a datum line (shown as a horizontal broken line for the sake of simplicity) may be assumed such that the rate of energy release at the line is that required to maintain steady combustion, then the heat release rates above the line are excessive and tend to produce abnormal combustion conditions. The intersections of the datum line and the heat release rate curves denote the points where pressure oscillations would become negligible and thereby define the equivalence ratio limits of an instability region. From Fig. 2, for methane-air the limits on equivalence ratio are 0.6 and 1.35 for a chamber pressure of 65 psia. At some low chamber pressure, the datum line is tangent to the top of the heat release curve. The point of tangency defines the toe of the instability region. From Fig. 2, for methane-air the toe is at an equivalence ratio of 0.9 and a chamber pressure of 41 psia. It is evident from Fig. 5 that for a given datum line the bounds of the instability regions of the fuels of higher reactivity cover a wider range of equivalence ratio. This is demonstrated experimentally by the data of Fig. 2, where hydrogen-air having the greatest reactivity has the largest instability region; methane-air is the least reactive and has the smallest region.

In References (1), (2), and (3) the shift of instability regions for ethylene-air propellants was explained as being due to an interaction between longitudinal and transverse modes at a length/diameter ratio of approximately 1.0. It appears reasonable that the same type of interaction caused the amplitude shift observed in Fig. 3. The methane-air propellants did not exhibit such shifts thus demonstrating another influence of the chemistry of the propellant combination.

Using the proposed combustion oscillation mechanism, the amplitudes of the pressure oscillations are dependent upon the amount of the excess heat release rate. Since the heat release rates are larger for the more reactive fuels, amplitudes of oscillation should be proportional to the fuel reactivity as is indicated in Fig. 4. It is also apparent from Fig. 4 that the amplitudes of the oscillations for all propellants increase with chamber pressure. This may be attributed to the increase in heat release rate due to the increase in propellant density at the increased chamber pressures.

Figure 4 clearly illustrates the relative maximum amplitudes of the three propellant combinations as a function of chamber pressure. Whereas the amplitudes of the oscillations for the hydrogen-air propellants change abruptly at low chamber pressures, the amplitudes of oscillation obtained with the other two propellant combinations increase somewhat more gradually as chamber pressure increases. It is interesting to note that as chamber pressure increases the ratio of the maximum amplitudes of oscillation for any two of the propellant combinations converges to a nearly constant value which closely approximates the ratio of laminar flame velocities[8] of the propellants; the latter being determined at a stoichiometric fuel/air ratio. In other words, at a chamber pressure where the amplitude ratio has met the above condition of convergence #E

$$\frac{P_a}{P_b} = K \frac{S_{ua}}{S_{ub}}$$

where P = amplitude of the pressure oscillation,

S_u = laminar flame velocity,

K = a proportionality constant.

Subscripts a and b refer to propellant combinations A and B respectively, where combination A is more reactive than B.

For the range of chamber pressures and the propellant combinations investigated, the value of K was very nearly 1.0. Some variation in the value of K would be expected by using flame velocities from different sources, by considering the pressure dependence of laminar flame velocity, etc.

It is also interesting to note that the results indicate that the number of different transverse modes which a propellant combination is capable of sustaining appears to be a function of the reactivity of the fuel as well as a function of the combustion chamber geometry. In the chamber pressure range investigated, the saturated hydrocarbons sustained only the fundamental transverse modes while the unsaturated hydrocarbons and also hydrogen were capable of sustaining combinations of modes, and modes higher than first order.

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CONCLUSIONS

Consideration of the relative reactivities and heat release rates of the fuels used in these experiments explain the following combustion oscillation phenomena for a premixed gaseous propellant system:

1. Saturated hydrocarbons exhibit less tendency to cause oscillations than the unsaturated hydrocarbons and hydrogen.

2. The magnitude of the lower critical length for the longitudinal mode of oscillation is smaller for the more reactive fuels.

3. When the lower critical length of the longitudinal mode is exceeded, it is highly probable that there will be an interaction between the longitudinal and transverse modes, which may cause a shift in the instability region, and amplitudes of oscillation which are higher than normal. For the highly reactive fuels this occurred at shorter chamber lengths than for less reactive fuels.

4. The characteristics of the instability region are influenced by fuel reactivity. Increasing the fuel reactivity causes

   a. a broadening of the range of equivalence ratios for the instability region;

   b. a lowering of the chamber pressure at which the instability region originates;

   c. an augmenting of the amplitude of the pressure oscillations within the instability region.

5. Whereas relatively unreactive saturated hydrocarbon fuels may support a single fundamental transverse mode, more reactive fuels are capable of sustaining more than one fundamental mode simultaneously as well as second order modes.

END OF ARTICLE

APPENDIX A

Selected Combustion Properties

Methane, ethane, and propane are members of the paraffinic series of saturated hydrocarbons. Ethylene is an unsaturated hydrocarbon with a double bond. Hydrogen, of course, is an elemental member of the hydrocarbon regime. Considering laminar flame velocity, heat release rate, and activation energy as the measure of reactivity, the fuels in order of decreasing reactivity are hydrogen, ethylene, propane, ethane, and methane. It has been shown by Reynolds and

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8. The values of laminar flame velocity should be determined by the same method. For values of laminar flame velocity determined by the "bunsen burner" method, refer to References (10) and (13).

A-7. EVALUATION OF QUESTIONS FOR WHICH NO COMPLETE ANSWER WAS RETRIEVED

2. What is the maximum flame temperature for the diborane liquid oxygen system?

   Retrieved: Doc. 2. Judged irrelevant.
   The article discussed thermodynamic properties of several fuel-liquid oxygen systems, but the diborane-LOX combination was not among them.

19. Is diborane soluble in butane or pentane to the extent of at least 5 mole per cent?

    Retrieved: Doc. 23. Answer can be inferred
    The data was expressed as mole fraction diborane per atmosphere, from which mole percent can be derived.

20. How can diborane by synthesized?

    Retrieved: Docs. 10, 13, 16, 39, 62, 63. Judged irrelevant.
    Docs. 11, 22, 24. Contained partial answer.
    Several methods of preparation are briefly discussed in these reports, but no experimental details are given.

22. Polyethylene is combustible with what mixtures of oxygen and nitrogen at ambient pressure?

    Retrieved: Doc. 28. Contains partial answer.
    No information on pressure was retrieved.

25. What is the mechanism of pentaborane decomposition at high temperature?

    Retrieved: Docs. 33, 81. Contain partial answer.
    Materials resulting from pentaborane decomposition are described, but no details are given on the mechanism by which the decomposition is effected.

29. What are the combustion limits of the hydrazines?

    Retrieved: Doc. 42. Contained partial answer.
    Doc. 47. Judged irrelevant.
    The responsive document did not contain information on the upper flammability limits.

31. How much does air collection increase the specific impulse of rocket systems?

Retrieved: Doc. 43. Answer can be inferred from the contents. The document contains equations and charts from which an answer can be derived.

32. All information on combustion of boron hydrides.

Retrieved: Doc. 69. Judged irrelevant.
Docs. 8, 11, 12, 16, 22, 39, 81. Contained partial answer.
Because of the form of the question, a complete answer is in theory unobtainable.

35. List the heats of formation of chemical compounds.

Retrieved: Doc. 49. Contains partial answer.
Because of the form of the question, a complete answer is in theory unobtainable.

37. What are the known beryllium propellants in use in the USSR?

Retrieved: Doc. 52. Judged irrelevant.
The article states only that beryllium propellants are in use in the USSR; no information on specific types of beryllium propellants is given.

40. What catalyst can be used to decompose hydrazine spontaneously?

Retrieved: Doc. 56. Judged irrelevant.
Doc. 7. Contains partial answer.
The catalyst described decomposes hydrazine only very slowly.

A-8. TABLES OF DISTRIBUTION OF FRAGMENTS

1. When the complete answer occurred in the document the distribution of fragments among the answer classifications was:

	Complete Answer	Answer can be Inferred	Partial Answer	Irrelevant	Not Retrieved
A	10	2	3	5	2
B	16	1	2	3	0
C	12	2	3	4	1
D	8	0	3	5	6

2. When the answer could be inferred from the document the distribution of fragments among the answer classifications was:

	Complete Answer	Answer can be Inferred	Partial Answer	Irrelevant	Not Retrieved
A	0	2	0	1	1
B	0	3	1	0	0
C	0	1	1	1	1
D	0	0	1	1	2

3. When a partial answer occurred in the document the distribution of fragments among the answer classifications was:

	Complete Answer	Answer can be Inferred	Partial Answer	Irrelevant	Not Retrieved
A	0	0	6	7	0
B	0	0	11	2	0
C	0	0	9	3	1
D	0	0	6	2	5

A-9. EFFECTIVENESS SCORING OF FRAGMENT RETRIEVAL RESULTS

The procedure of scoring retrieval effectivness developed in Section 7 will be applied to the results of the fragment retrieval study. We use formula (39) p. 79. First we calculate $\overline{R}$, the mean proportion of relevant sentences retrieved, and $\overline{I}$, the average number of irrelevant sentences retrieved. The issue now is how to calculate $\overline{p}$ (the penalty coefficient). To do this we use the formula (12) p. 73. The argument is as follows: if the retrieved fragment does not answer the user's question, then the alternative is to read the complete document. Let t be the total number of sentences in the document and let m of these be relevant. Thus k = t in formula (12). It is then easily shown that

$$f(n, x) = R - \frac{1}{t-m} I .$$

Thus $p = \frac{1}{t-m}$. The calculations show $\overline{p} = .0158$.

The calculations for $\overline{R}$, $\overline{I}$, $\overline{f}$ (the final effectiveness score) are shown below:

	A Extract Sentence	B Document Sentence	C Document Paragraphs	D Extracts	Full Text of Document
$\overline{R}$	.28	.58	.26	.39	1.00
$\overline{I}$	6.7	15.1	7.1	15.5	63.4
$\overline{f}$	.17	.34	.15	.15	0

Comparable effective figures for the maximally relevant sentences (those which constitute a minimal complete answer) were also computed:

	A	B	C	D	E
$\bar{f}$	.28	.54	.30	.27	0

It is seen that the effectiveness is roughly twice as great when calculated for only the maximally relevant sentences.

APPENDIX B

INFORMATION CORRELATION STUDY

B-1. FRAGMENTS IN THE F_1 STAR

1. Space mission studies have indicated the need for small rocket motors of low thrust (of the order of 100 lb) for attitude control, midcourse trajectory corrections, rendezvous, and so forth.

2. The research conducted in supersonic wind tunnels on rocket exhaust and related external-flow problems of missiles and space-vehicle boosters has established a need for small-scale rocket engines.

3. Based on the evaluation of the effects of additives on the flashback limits of the additive-fuel blends tested in the microburner (Model 1A) it is recommended that dimethylamine borine should be further investigated.

4. Evaluation of the Effect of Dimethylamine Borine and Several Other Additives on Combustion Stability Characteristics of Various Hydrocarbon Type Fuels in Phillips Microburner.

5. These engines are suitable for use in wind-tunnel models of missiles or vehicle boosters and offer a compact unit for cluster arrangement and directional control.

6. Small size, high-performance rocket engines have been developed.

7. Rocket engines for missile and space-vehicle models must have external dimensions that permit their clustering and gimbaling in a spaced relation determined by the thrust scale factor.

8. Also, many of the new high performance propellants which are particularly toxic and hazardous require special valving, gasket materials, and handling procedures which can be accomplished more easily and rapidly on a small motor.

9. It was with these thoughts in mind that the small motor was developed to a point where the performance of the inhibited red fuming nitric acid (IRFNA) - unsymmetrical dimethylhydrazine (UDMH) system compares favorably with similar test motors at other facilities and the difference in performance of about 4 percent can be distinguished between systems such as IRFNA-hydrazine (N_2H_4) and IRFNA-UDMH.

10. However, this must be supplemented with a small motor to evaluate new propellants available only in small quantities.

11. The combustion gases are cooled to a much greater extent relative to that in a larger motor, thus lowering c* (characteristic velocity).

12. A complete description of the micro-rocket motor used is given in the Final Report on the above contract.

13. E. Calibration of the Micro-Rocket Motor Using JP-4 Liquid Oxygen (LØX)

14. The ratio of the cooling area to the volume of the chamber is very high ($\frac{A}{V} = 4$), as would be expected, for this small motor.

15. The relatively low cost of the development of a new vehicle for upper-stage application as compared to the total cost of the space program emphasizes the importance of propulsion-system performance and reliability.

16. It is evident from a comparison of the relative costs of a space program that the dominant cost factors are those associated with the operation of the launch site and tracking facilities and procurement and preparation of the payload and the initial booster stage; successive upper stages contribute a less and less significant portion of the overall program cost.

17. This motor uses small quantities of propellants which can be made on a laboratory scale yet is large enough that the heat transfer losses are small.

18. Small, compact rocket engines with a high degree of reliability for continual operation were developed for wind-tunnel missile and space-vehicle-booster models.

19. In general, additive concentrations of one percent by weight in the several pure hydrocarbons which normally differed quite widely in performance, produced uniformly superior combustion stability characteristics as measured using the Phillips microburner.

20. Low thrust devices velocity control experimental program/ catalytic decomposition of hydrazine

21. The addition of dimethylamine borine in concentrations of one percent by weight to jet fuel type hydrocarbons resulted in a uniformly high level of combustion stability performance as measured by Phillips microburner.

22. II. Description of Phillips Microburner (Model 1A)

23. Due to the small quantity of this material obtained the evaluation was conducted in the Phillips microburner (Model 1A) which is a slightly modified version of the original Phillips microburner (Model 1).

24. There are discussed the characteristics of a small hydrazine-nitrogen tetroxide rocket motor, developed by RMD that would be suitable for experimentation.

B-2. CONCEPTS USED FOR DEVELOPMENT OF CORRELATION MATRIX

2.

supersonic
wind tunnel
exhaust
flow
airflow
missiles and rockets
space-vehicle
booster

3.

evaluation
additive
addition
flashback
fuel
propellant
gases
test
dimethylamine borine

4.

evaluation
dimethylamine borine
additive
combustion
stability
hydrocarbon
fuels
propellants
gases

5.

wind tunnel
models
missiles and rockets
cluster arrangement
space-vehicle
booster
directional control
attitude
gimbal

6.

performance
rocket
development

7.

rocket and missile
clustering
space-vehicle
models
dimensions
gimbaling, etc.
thrust

8.

performance
propellants
fuels
gases
toxic
hazardous
valving
gasket
handling procedures
ease, efficient

9.

performance
IRFNA
UDMH
hydrazine
evaluation
test
system
facilities

10.

evaluation
propellants
new
quantities

11.

combustion
gases
propellants
fuels
cobling
heat transfer
c*
characteristic velocity

12.

description
rocket
final report
contract

13.

calibration
rocket
JP-4
hydrocarbon gases
LØX

15.

cost
develop
vehicle
new
upper stage
performance
reliability
propulsion system

16.

cost
operation
launch-site
tracking
procurement
payload
booster
upper-stage

17.

quantities
propellants
fuel
laboratory
heat transfer

18.

rocket
reliability
wind-tunnel
developed
space-vehicle
booster
model
operation

19.

additive
hydrocarbons
performance
combustion
stability
measured

20.

thrust
velocity
experimental
catalytic
decomposition
hydrazine

21.

addition
dimethylamine borine
jet fuel
hydrocarbons
combustion
stability
performance
measured

22.

description

23.

quantity
evaluation
modify
version

24.

hydrazine
nitrogen tetroxide
rocket
developed
experimentation

B-3. CLUSTERS USED IN CORRELATION EXPERIMENTS

STRONG CLUSTERS

S-1	1	2	5	7	8	18
S-3	1	6	15	18		
S-5	1	9	15			
S-14	1	18	24			
S-15	1	10	17			
S-16	1	11	17			

WEAK CLUSTERS

W-1	1	11	14	17			
W-3	1	7	20	24			
W-5	1	3	4	9	10	23	
W-6	1	3	4	10	17	23	
W-9	1	2	5	7	15	18	
W-11	1	2	6	7	15	18	24
W-12	1	3	4	8	10	17	21
W-17	1	9	15	16			
W-22	1	6	9	15	24		

B-4. INSTRUCTIONS FOR CORRELATION EXPERIMENTS

This experiment will require four participants who will be identified by the Roman numerals I-IV on the manila folders.

The materials furnished each participant consist of four folders labeled A, B, C, and D, each of which contains data for three experiments. These experiments involve two steps: (1) reading specified material; (2) listing inferences derived from this reading. Time limits will be given for each step. Procedure for carrying out the experiments is as follows (examples are for person I):

1. Take folder A. Read the documents listed for the first experiment (W-1, in this case). Considering the group of documents as a whole, list inferences that can be derived. This list should be labeled with experiment number (W-1), the level number (A), and the participant number (I). (For maximum reading and inference times, see table below). Then proceed with the next two "A" experiments in the same manner.

2. Take folder B. Proceed as with A, reading document abstracts given for each experiment and listing inferences derived from the set of abstracts as a whole.

3. Take folder C. Experiment numbers are marked in red on the first of the data sheets for each experiment. Considering each stapled group of sheets as a whole, proceed as with levels A and B, observing given times.

4. Take folder D. One sheet of data, which is numbered in red on the top, is given for each experiment. Proceed as above with time limits given below.

Table of Maximum Times

Level	Reading Time	Time for Deriving Inferences
A	One-half hour	20 minutes
B	20 minutes	20 minutes
C	15 minutes	20 minutes
D	5 minutes	20 minutes

This table lists the maximum times allowable for each separate experiment. Thus, for experiment W-1 on level A, participant I is allowed one-half hour reading time and 20 minutes for deriving inferences. For experiment W-3 on level A, the same amount of time is allowed, and so on.

B-5.1. INFERENCES DERIVED BY PARTICIPANT II

II-A-W-11

1. Most pressure fed propulsion systems operate at chamber pressures which are less than 300 psi.
2. Combustion efficiencies of approximately 94-96.5% are typical for many propellant combinations.

II-A-W-17

1. Most pressure fed propulsion systems operate at chamber pressures which are less than 300 psi.
2. Combustion efficiencies of approximately 94-96.5% are typical for many propellant combinations.
3. Propellant evaluations do not appear to be standardized.

II-A-S-16

1. Propellant evaluations do not appear to be standardized.

II-B-S-1

1. There are many applications for small rocket engines.
2. There appears to be a proportionality between thrust level and L*.
3. 94% efficiency, or better, can be expected for many propellant combinations.

II-B-S-3

1. Both analytical and experimental efforts are necessary to evaluate propellant combinations.

II-B-S-14

1. Both analytical and experimental efforts are necessary to evaluate propellant combinations.

II-C-W-22

1. Reliability, performance, cost, ignition characteristics, heat transfer characteristics, engine size, system limits, mission requirements, and development time must be considered when selecting a propulsion system.

   or, a propulsion system must be evaluated both analytically and experimentally.

II-C-S-5

1. When performing mission analyses, propellant performance of 94% can be assumed for most propellant combinations.

II-C-S-15

1. 94%, or better, can be expected as the performance for many propellant combinations.

2. There are many applications for small rocket engines.

II-D-W-1

1. To satisfy the need for low thrust rocket engines (i. e. < 100 lbs) severe problems of heat transfer and low performance must be overcome.

II-D-W-3

1. There are many applications for low thrust rocket engines.

II-D-W-5

1. Small scale rocket engines should be standardized for the evaluation of new propellants.

B-5.2. LEVEL D CLUSTERS FOR PARTICIPANT II

W-1

Space mission studies have indicated the need for small rocket motors of low thrust (of the order of 100 lb) for attitude control, midcourse trajectory corrections, rendezvous, and so forth.

The ratio of the cooling area to the volume of the chamber is very high ($\frac{A}{V} = 4$), as would be expected, for this small motor.

The combustion gases are cooled to a much greater extent relative to that in a larger motor, thus lowering c (characteristic velocity).

This motor uses small quantities of propellants which can be made on a laboratory scale yet is large enough that the heat transfer losses are small.

W-3

Low thrust devices velocity control experimental program/catalytic decomposition of hydrazine

Rocket engines for missile and space-vehicle models must have external dimensions that permit their clustering and gimbaling in a spaced relation determined by the thrust scale factor.

Space mission studies have indicated the need for small rocket motors of low thrust (of the order of 100 lb) for attitude control, midcourse trajectory corrections, rendezvous, and so forth.

There are discussed the characteristics of a small hydrazine-nitrogen tetroxide rocket motor, developed by RMD that would be suitable for experimentation.

W-5

Space mission studies have indicated the need for small rocket motors of low thrust (of the order of 100 lb) for attitude control, midcourse trajectory corrections, rendezvous, and so forth.

It was with these thoughts in mind that the small motor was developed to a point where the performance of the inhibited red fuming nitric acid (IRFNA) - unsymmetrical dimethylhydrazine (UDMH) system compares favorably with similar test motors at other facilities and the difference in performance of about 4 percent can be distinguished between systems such as IRFNA-hydrazine (N_2H_4) and IRFNA-UDMH.

However, this must be supplemented with a small motor to evaluate new propellants available only in small quantities.

Due to the small quantity of this material obtained the evaluation was conducted in the Phillips microburner (Model 1A) which is a slightly modified version of the original Phillips microburner (Model 1).

Evaluation of the Effect of Dimethylamine Borine and Several Other Additives on Combustion Stability Characteristics of Various Hydrocarbon Type Fuels in Phillips Microburner

Based on the evaluation of the effects of additives on the flashback limits of the additive-fuel blends tested in the microburner (Model 1A) it is recommended that dimethylamine borine should be further investigated.

B-6.1. S-16 CLUSTER

This motor uses small quantities of propellants which can be made on a laboratory scale yet is large enough that the heat transfer losses are small.

The combustion gases are cooled to a much greater extent relative to that in a larger motor, thus lowering c (characteristic velocity).

Space mission studies have indicated the need for small rocket motors of low thrust (of the order of 100 lb) for attitude control, midcourse trajectory corrections, rendezvous, and so forth.

B-6.2. INFERENCES FOR CLUSTER S-16

B-6.2.1 Inferences at A-level (Participant II)

1. Propellant evaluations do not appear to be standardized.

B-6.2.2 Inferences at B-level (Participant I)

1. Hypergolic rocket propellants permit optimum utility of small thrust engines.

2. Injector configuration is a critical parameter in achieving maximum performance of small, low thrust rocket engines.

3. High energy, toxic rocket propellants can be handled without hazard.

B-6.2.3 Inferences at C-level (Participant IV)

1. Propellants can deteriorate upon standing over long periods of time.

2. Impurities may be the cause of uncontrolled burning and/or detonations and decrease performance of propellants.

3. In small motors heat transfer through components lower performance significantly.

4. Better mixing of propellants increases performance.

5. N_2O_2 and N_2H_4 are the best state-of-the-art combinations which satisfy requirements.

6. Testing on small sub-scale is sufficient for accepting or rejecting a propellant combination for use on larger motor tests.

B-6.2.4 Inferences at D-level (Participant III)

2. Low thrust, efficient, simple, rocket motors have a variety of potential research and development applications.

12. In a small motor combustion gases are cooled to a greater extent than in a large motor probably because of the greater ratio of heat transfer surface to combustion chamber volume in the small motor.

B-7. INFERENCES INDEXED UNDER HEAT TRANSFER

IV-C-S-16

3. In small motors heat transfer through components lower performance significantly.

III-D-S-16

12. In a small motor combustion gases are cooled to a greater extent than in a large motor probably because of the greater ratio of heat transfer surface to combustion chamber volume in the small motor.

II-D-W-1

1(a) To satisfy the need for low thrust rocket engines (i. e. < 100 lbs) severe problems of heat transfer must be overcome.

I-D-S-15

1. The requirement of small, low thrust rocket engines for space mission studies necessitates further investigation to evaluate new propellants on a scale large enough to minimize heat transfer losses.

IV-B-W-1

7. Heat transfer losses on the small motors are large.

IV-A-S-15

4. Heat transfer losses must be considered when computing performance data on small motors.

B-8. Table of Classification of Inferences

No.	Category	W-22	W-17	W-11	W-5	W-3	W-1	S-16	S-15	S-14	S-5	S-3	
		D C B A	D C B A	D C B A	D C B A	D C B A	D C B A	D C B A	D C B A	D C B A	D C B A	D C B A	D C B A
1	Problems	A 1									A 1		
2	Propellant Evaluations		A 1		D 1			A 1	A 1	B 1		B 1	
3	Propellant Combinations			C 1				C 2		D 2, A 1	A 2		
4	Propulsion Systems	C 1, A 1											
5	Storage and Handling						B 3	C 1, B 1	A 3	D 1			
6	Extrapolation of Test Results	B 1					C 1, B 1		B 1		B 1, A 1		
7	Design			C 2		B 1	B 1						
8	Chambers		A 1	A 1									
9	Combustion Efficiency	B 1	A 1	A 1	B 1		C 1		B 1	A 1	B 1	A 1	B 1, A 1
10	Combustion Stability				C 2, B 3, A 2								
11	Ignition	B 1				C 1, A 1				A 2		A 2	A 2
12	Heat Transfer						D 1, B 1	D 1, C 1	D 1, A 1				
13	Reliability		C 2	C 1						D 1		D 2	D 1
14	Performance (General)		B 1				D 1				A 1		
15	Performance (Fuel Injection)	B 1	B 1		A 1		B 1, A 1	B 1	A 1	C 1, A 1		A 1	C 1, A 1
16	Performance (Propellants)	A 2	C 1	C 1		B 1, A 1	A 1	C 2	C 1		C 1, A 1		
17	Applications for Small Motors (General)	B 1, A 1	D 1, C 1	D 1, C 1		D 1, C 1, A 1	C 1	C 1	C 1, B 1	A 1	B 1, A 1	A 1	B 1, A 1
18	Applications for Small Motors (Optimum Utility)			B 1				B 1					
19	Applications for Small Motors (Non-space)	B 1				C 1				A 1			
20	Applications for Small Motors (General Military)			C 1		B 1							
21	Applications for Small Motors (Military Equipment)	A 1				B 1							
22	Applications for Small Motors (Space, General)	D 1	B 1	B 1		B 1	A 1				D 1	C 2	C 1
23	Applications for Small Motors (Space, Specific)											D 1	
24	Applications for Small Motors (Space, Control)	A 1		C 1		B 1				D 1		D 1	D 3